POSTURAL AND PERCEPTUAL MEASUREMENTS DURING PERFORMANCE OF STATIC STANDING BALANCE EXERCISES

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Purpose: Balance training has shown benefits in improving balance in older adults and people with vestibular disorders. However, the evidence for determining the appropriate intensity and progression of balance exercises is very limited. The purpose of this study was to develop a method for quantifying intensity of balance exercises, and to determine guidelines for progressing exercises.

Participants: Sixty-two healthy subjects who were between the ages of 18 and 85 years old (50% female, mean age 55 ± 20 years), and eight participants with vestibular disorders (50% female, mean age 56 ± 16 years) were enrolled in the study.

Methods: Healthy subjects were tested during two visits and performed two sets of 24 randomized static standing exercises in each visit. Participants with vestibular disorders were tested in one visit and performed two sets of 16 randomized static standing exercises. The exercises consisted of combinations of the following factors: surface (firm and foam), vision (eyes open and eyes closed), stance (feet apart and semi-tandem), and head movement (still, yaw, and pitch). Postural sway and ratings of perceived difficulty were measured for each exercise. The test-retest reliability of subjects' performance and their rating of perceived difficulty of different standing balance exercises was examined. Two scales of rating of perceived difficulty of balance exercises were validated by comparing them with quantitative sway measures. The effects of age and vestibular disorders on postural and perceptual measures were tested using linear mixed models.

Results: Position and acceleration sway measures demonstrated acceptable test-retest reliability, while sway velocity measures were the most reliable. The rating of perceived difficulty scales demonstrated fair to substantial agreement with few exceptions. Moderate to strong positive correlations were observed between the rating of perceived difficulty and all sway measures, establishing their validity. Sway and ratings of perceived difficulty increased in older subjects. Individuals with vestibular disorders did not produce more sway compared with controls, but they did have higher ratings of perceived difficulty.

Conclusion: Quantitative sway measures and ratings of perceived difficulty can be used to prescribe the intensity of balance exercises and guide progression during rehabilitation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENT

This research is intended for physical therapists and other clinicians who provide balance interventions, in order to help them to accurately prescribe balance and vestibular exercises to their clients.

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1.0 INTRODUCTION

The likelihood of falling increases as people get older (Berry & Miller, 2008; Centers for Disease & Prevention, 2008; Cnters for Disease & Prevention, 2016; Tinetti, Doucette, Claus, & Marottoli, 1995) or if an individual has a vestibular disorder (Agrawal, Carey, Della Santina, Schubert, & Minor, 2009; Cohen, Heaton, Congdon, & Jenkins, 1996). Falling can be a life threatening issue especially for older adults as it might result in death or injuries such as a hip fracture (Berry & Miller, 2008; Centers for Disease & Prevention, 2008; Tinetti et al., 1995). Another adverse consequence for those who have fallen is developing a fear of falling which may result in a reduction in participation in daily life activities and being non-active members in their community (Tinetti, Mendes de Leon, Doucette, & Baker, 1994).

The human body is not completely still during upright stance, but in contrast, it demonstrates small amplitude motion, which is called postural sway. Despite the existence of this movement, the body remains stable as long as its center of mass (COM) remains over its base of support (Horak, 1987). One of the factors that increases postural sway is getting older (Baloh et al., 1994; Baloh, Jacobson, Enrietto, Corona, & Honrubia, 1998; Gill et al., 2001; Liaw, Chen, Pei, Leong, & Lau, 2009; Rogind, Lykkegaard, Bliddal, & Danneskiold-Samsoe, 2003; Sheldon, 1963; Sullivan, Rose, Rohlfing, & Pfefferbaum, 2009). Another factor that affects postural sway adversely is sustaining a vestibular disorder (Baloh et al., 1998; Fujimoto et al., 2014).

Customized balance exercises and vestibular rehabilitation therapy (VRT) are considered to be effective options to improve balance by facilitating the central nervous system’s ability to compensate for balance deficits (Hillier & McDonnell, 2011; Horak, Jones-Rycewicz, Black, &

Shumway-Cook, 1992; Shepard & Telian, 1995). These treatments have elicited beneficial results in improving balance in older adults and people with vestibular disorders, eliminating the symptoms of vestibular disorders, and reducing falls (Hillier & McDonnell, 2011; Horak et al., 1992).

Balance and vestibular rehabilitation therapy is comprised of different categories of exercises such as static standing, weight shifting, anticipatory postural adjustments, gait, and eye-head coordination (Alsalaheen et al., 2013). Each of the exercises in these categories can be performed in different ways by manipulating various modifying factors, such as the use of visual feedback, different sizes of base of support, and head movements (Alsalaheen et al., 2013). Some of these exercises and conditions are considered to be more difficult than others, in terms of causing a loss of balance or increasing sway. Typically, a physical therapist will intuitively progress the challenge of balance exercises during rehabilitation by using different combinations of the modifying factors based on clinical experience. For instance, static standing balance exercises may be progressed from eyes open to eyes closed, from a stable surface to an unstable surface such as a foam cushion, or from a plain visual background to the complex visual background such as a checkerboard pattern. Walking exercises may be progressed by decreasing the base of support in the medial-lateral direction or by closing the eyes. The progressions have justification based on theoretical concepts, experimental evidence, and clinical experience. However, quantification of the postural measures elicited by different across a comprehensive set of modifying factors has not yet been studied in the same experiment. By measuring the trunk tilt and center of pressure produced during these different exercises, we will have a standard way of assessing the level of difficulty of the exercises, which may facilitate better treatment progression algorithms used in practice and research. In addition, these measures have not been compared with subjects' rating of perceived difficulty.

The purpose of this study is to record trunk tilt, center of pressure, and perceived difficulty during a wide variety of static standing exercises commonly performed in balance and vestibular rehabilitation. By using the postural and perceptual measures during standing exercises, we will be able to determine the relative difficulty of each exercise, and validate common rubrics for treatment progression. In addition, the effect of age on postural and perceptual measures will also be examined. A secondary aim is to record sway of individuals with vestibular disorders as they perform the exercises. Finally, I will be looking at the reliability of subjects' performance of these exercises within and between 2 visits, performed 1 week apart.

1.1 SPECIFIC AIMS

1.1.1 Specific aim 1

To examine the test-retest reliability of the subjects' performance of standing balance exercises, within and between two visits occurring one week apart.

1.1.2 Specific aim 2

To validate two rating scales of perceived difficulty of balance exercises by comparing the scales with quantitative sway measures.

Hypothesis 1: On a within-subject basis, rating of perceived difficulty will increase as trunk tilt increases.

1.1.3 Specific aim 3

To examine the perceived difficulty and postural measures of static standing balance exercises in healthy adults from 18 to 85 y/o.

Hypothesis 1:

During the performance of balance exercises, trunk tilt sway measures and rating of perceived difficulty will increase from the youngest to the oldest age group.

Hypothesis 2:

Trunk tilt sway measures and rating of perceived difficulty will increase as static stance balance exercises change from: level surface to foam surface, eyes open to eyes closed, head still to yaw or pitch movement, and feet apart to semi-tandem stance.

Hypothesis 3:

The increase in magnitude of trunk tilt sway measures will be greater as age increases and as static stance balance exercises change from: level surface to foam surface, eyes open to eyes closed, head still to yaw or pitch movement, and feet apart to semi-tandem stance.

1.1.4 Specific aim 4

To examine the effect of vestibular disorders on the magnitude of trunk tilt and rating of perceived difficulty during performance of different types of static standing balance exercises.

Hypothesis 1:

Individuals with vestibular disorders will have greater trunk tilt and rating of perceived difficulty during the performance of standing balance exercises compared with healthy age-matched controls.

Hypothesis 2:

Individuals with vestibular disorders will have an increase in postural sway and rating of perceived difficulty as static standing balance exercises change from level surface to foam surface, eyes open to eyes closed, head still to yaw movement, and feet apart to semi-tandem stance.

Hypothesis 3:

The increase in magnitude of trunk tilt and rating of perceived difficulty as static stance balance exercises change from: level surface to foam surface, eyes open to eyes closed, head still to yaw movement, and feet apart to semi-tandem stance, will be greater in individuals with vestibular disorders compared with healthy age-matched controls.

2.0 BACKGROUND

2.1 BALANCE

Balance is defined as the ability to maintain the upright position during static stance or dynamic activities such as walking or running. Body balance while performing various activities depends on the sensory information received from the eyes, sensory receptors in joints and muscles, and vestibular apparatus.

Vision provides information to the brain about the body location in the surrounding area and surrounding obstacles that might disturb balance. The sensory receptors in the muscles and joints contribute to balance by sending information to the brain about the movement of limbs which helps the brain to take appropriate motor actions to avoid the loss of balance. In addition, the vestibular system contributes important information about the linear and angular movement of the head with respect to the body.

The peripheral sensory organs send information to the brain to be integrated with each other and linked with the control and coordination area in cerebellum and the thinking and memory areas (Day, Guerraz, & Cole, 2002; Dozza, Chiari, & Horak, 2005; Horak, 2006; Rowell, Shepherd, & American Physiological Society, 1996; Rowell, Shepherd, & American Physiological Society (1887-), 1996). After the integration of sensory information, the brain executes the appropriate motor action by moving the muscles of the neck, trunk and limbs to keep the body balanced, as well as to maintain fixation on a target during head movement.

It has been found that the somatosensory system contributes more than the visual and vestibular system to the maintenance of balance across all age groups (Colledge et al., 1994;

Lord, Clark, & Webster, 1991a; Lord & Ward, 1994). However, there is variation in the relative amount of contribution between and within different age groups. For example, studies support that young children and older adults use vision to a greater degree than young adults. A study reported that the visual contribution to postural control starts from 3 years of age and increases until 6 years of age, although this contribution diminished at 7 years of age and increased again at 8 years of age to adulthood (Assaiante, 1992). In addition, older adults over the age of 55 years sway more when vision is altered, which supports the fact that older adults rely heavily on feedback from vision (Peterka & Black, 1990). Interestingly, the same study reported increased sway in children up to 20 years of age during conditions requiring vestibular control (Peterka & Black, 1990).

Balance disorders due to aging or due to disease and injury within the central nervous system or peripheral balance organs may lead eventually to falling (N. B. Alexander, 1994). Oliveira et al. compared patients with stroke within a year with healthy people and found that patients had worse scores on the Berg Balance Scale and Sensory Organization Test and also found a link between stroke and history of falls (Oliveira et al., 2011).

As people get older they demonstrate age-related decline in sensory systems (Kerber, Ishiyama, & Baloh, 2006; Lichtenstein, Shields, Shiavi, & Burger, 1988; Lord et al., 1991a; Lord & Ward, 1994; Ring, Nayak, & Isaacs, 1989; Serrador, Lipsitz, Gopalakrishnan, Black, & Wood, 2009), brain structural abnormalities and related cognitive function reduction (Baloh, Ying, & Jacobson, 2003; Sullivan et al., 2009; Tell, Lefkowitz, Diehr, & Elster, 1998), and lower limb muscle weakness (Aniansson, Hedberg, Henning, & Grimby, 1986; Dean, Kuo, & Alexander, 2004; Larsson, Grimby, & Karlsson, 1979; Lord et al., 1991a). All may lead to poor postural stability and higher risk of falling. In accordance, sustaining a vestibular disorder contributes to increasing postural instability (Baloh et al., 1998).

In this review, I will review the research about postural sway and its relation to aging and having vestibular disorders. Also, I will address the effect of performing different balance exercises on postural sway.

2.2 FALLS

Falling is one of the leading causes of serious injuries or even death among older people (Berry & Miller, 2008; Centers for Disease & Prevention, 2008; Tinetti et al., 1995; Tinetti & Williams, 1998) and falls occur more frequently as people get older (Berry & Miller, 2008; Centers for Disease & Prevention, 2008; Cnters for Disease & Prevention, 2016; Sixt & Landahl, 1987; Tinetti et al., 1995; Woollacott, Shumway-Cook, & Nashner, 1986). The likelihood of falling increases when people reach 60 years or older as reported by Rubenstein (Rubenstein et al., 1988). Falls among older adults may lead to serious injuries such as hip fractures (Berry & Miller, 2008; Centers for Disease & Prevention, 2008; Tinetti et al., 1995). Consequently, about 25% of those who have a hip fracture die within a year (Forsen, Sogaard, Meyer, Edna, & Kopjar, 1999). The probability of longer hospital stays for those who fall increases four to five times in people older than 75 years compared to people of age 65 to 74 years (Scott, 1990). Over a 4 year period, the average length of stay in the hospital because of fall–related injuries was greater than the average length of stay for all other reasons for those who were 65 years and older (Public-Health-Agency-of-Canada, 2014). According to the Centers for Disease Control and Prevention (CDC), in some cases falls may lead to death due to fatal injury (CDC, 2014).

Falls cost the medical care system in the USA about 30 billion dollars in 2010 (Stevens, Corso, Finkelstein, & Miller, 2006b). By 2020, the CDC expects that the medical care's cost of fall injuries in the USA will reach approximately 54 billion dollars annually.

Several risk factors of falling have been reported in many studies. Usually, these risk factors are classified into two different groups: extrinsic and intrinsic risk factors. Extrinsic factors result from the surrounding environment such as poor lighting and unstable walking surface, while intrinsic factors are considered a result of the physiological changes associated with aging (Lajoie & Gallagher, 2004) or diseases. Identifying risk factors of falling have helped to predict who is at risk of falling and have directed the clinical interventions whose goal is to reduce the number of future falls (Hilliard et al., 2008). One of the important intrinsic risk factors is an increase in postural sway which has been reported to be one of the predictors of falling among older adults (C. J. Chang, Chang, & Yang, 2013; Hilliard et al., 2008; Maki, Holliday, & Topper, 1994). For instance, the displacement of center of pressure (COP) helps to predict which older adults will fall compared to healthy peers (C. J. Chang et al., 2013). Maki et al. did a prospective study for one year to assess the ability of different clinical and laboratory balance tests to predict risk of future falling. Among the laboratory balance tests, they found that lateral sway distinguishes optimally between fallers and non-fallers (Maki et al., 1994).

The increased rate of falls among elderly people leading to serious injuries and fatal injury-related deaths has stimulated researchers to explore the effect of changes in postural sway related to aging.

2.3 POSTURAL SWAY

Postural sway is the movement of the body even when standing at rest. Postural sway was found to be correlated with some clinical measures of balance such as Berg Balance Scale and one leg stand test (Lichtenstein, Burger, Shields, & Shiavi, 1990; Nguyen et al., 2012). Postural sway also can provide helpful information to identify people with a high risk of falling (Fernie, Gryfe, Holliday, & Llewellyn, 1982; Maki et al., 1994; Stalenhoef, Diederiks, Knottnerus, Kester, & Crebolder, 2002) as postural sway and number of falls are highly correlated (Hilliard et al., 2008; Nanhoe-Mahabier, Allum, Pasman, Overeem, & Bloem, 2012).

Centre of mass (COM) and center of pressure (COP) are parameters that are used to describe the control of body movement. The COM is the point where the body mass is distributed equally around it in the global reference system (GRS) (D. A. Winter, 1995). The center of gravity is the vertical projection of the center of mass onto the base of support (D. A. Winter, 1995; David A. Winter, 2009). On the other hand, COP is the point where the total sum of pressure field acts between a physical object and its supporting surface (D. A. Winter, 1995). Ankle plantar flexors and dorsiflexors are what control the movement of COP in the A/P direction whereas hip musculature primarily controls the COP movement in M/L direction (D. A. Winter, 1995). Practically, the COP position moves wider around the COG position and COP leads the movement of COG (D. A. Winter, 1995). There is a strong relationship between COG and COP as the difference between them is proportional to the horizontal acceleration of COM and therefore it is possible to estimate the location of COG with the COP by using low-pass filter (Brian J. Benda, 1994; Chiari et al., 2005; D. A. Winter, 1995).

The next section of this review will be concerned with the relationship between age, vestibular disorders, different balance exercises and postural sway.

2.3.1 Postural sway and aging

In the literature, both center of mass and center of pressure have been used as indicators of postural sway. It is well documented that an increase in postural sway is associated with increase in age (Baloh et al., 1994; Baloh et al., 1998; Gill et al., 2001; Rogind et al., 2003; Sheldon, 1963; Sullivan et al., 2009). Sheldon monitored the change in postural sway with aging and found that when people reach between 18 and 20 years of age they have the optimal control of postural sway and they maintain that until about the age of 60 (Abrahamova & Hlavacka, 2008; Sheldon, 1963) when it starts to decline (Era et al., 2006). Worsening of postural sway in elderly people can be a result of poor peripheral sensory systems: vision (Lichtenstein et al., 1988; Lord, Clark, & Webster, 1991b), somatosensation (Lord et al., 1991b), vestibular function (Kerber et al., 2006) brain structural changes and related cognitive function reduction (Baloh et al., 2003; Sullivan et al., 2009; Tell et al., 1998), lower limb muscle weakness and absence of protective reflexes (Aniansson et al., 1986; Larsson et al., 1979).

1- <u>Postural sway in older adults and deterioration of sensory systems inputs</u>

Increased postural sway has been reported in many studies to be associated with reduced vision (Lichtenstein et al., 1988; Lord & Ward, 1994; Ring et al., 1989), poor somatosensory inputs (Lord et al., 1991a; Lord & Ward, 1994; Ring et al., 1989), and deteriorated vestibular function (Kerber et al., 2006; Lord & Ward, 1994; Serrador et al., 2009). One of the age-related changes that leads to postural instability is decline in visual acuity (Gittings & Fozard, 1986). Lord reported that postural sway increases by 20–70% when people stand with their eyes closed (Lord, 2006). Accordingly, Ray et al. conducted a study to assess postural stability of 46 participants with mean of age 76 ± 13 years, by using the Sensory Organization Test (SOT), and found a significant decrease in equilibrium composite scores among the visually impaired participants (below the legal blindness limit) compared to sighted participants (Ray, Horvat, Croce, Mason, & Wolf, 2008). Another study by Lord et al. suggested that impaired vision is an important risk factor for falls (Lord & Dayhew, 2001).

Additionally, another important age-related risk factor for falling is reduced visual contrast sensitivity (VCS). Visual contrast sensitivity is the ability of vision to distinguish the difference in contrast. People need to maintain optimal VCS in order to avoid tripping over obstacles or objects in their environment during walking. A few studies which included different measures of vision found that the visual contrast sensitivity test is more important than measuring visual acuity in predicting who is at risk of falling (Lord, 2006; Lord & Dayhew, 2001).

Not only can poor vision in older adults affect the stability of the body, but also moving visual environments. A study conducted by Borger et al. found that body sway of older adults between the ages of 60 and 80 is more affected by dynamic visual environments during standing compared to younger adult subjects between 20 and 30 years, especially during standing on a moving platform and high amplitudes of scene movement (Borger, Whitney, Redfern, & Furman, 1999). Nevertheless, another study suggests that older adults can adapt to dynamic visual environments, but it requires them to have more repeated exposure to visual flow than young people (O'Connor, Loughlin, Redfern, & Sparto, 2008).

There is evidence of age-related changes in somatosensory modalities (Kaplan, Nixon, Reitz, Rindfleish, & Tucker, 1985; Shaffer & Harrison, 2007). Somatosensory modalities have an important role in maintaining balance, whereas disordered somatosensation may deteriorate postural sway. Lord et al. conducted a study of 95 people between 59 to 97 yrs. to assess postural sway during standing on firm or foam surface with eyes open or closed. They found greater sway during standing on a firm surface was associated with both decreased tactile sensation and proprioception. However, during standing on foam surface, increased postural sway was associated with decreased vibration sense and proprioception when the eyes were open, and decreased tactile sensation when the eyes were closed (Lord et al., 1991a).

Several studies found an interaction between age and distorted somatosensation (Liaw et al., 2009; Peterka & Black, 1990). These studies found no significant difference between older and younger groups when standing on a stable surface, whereas, a significant difference was found between groups when they stood on a tilted surface. In contrast, a recent article suggests that vibration stimuli applied to the tibialis anterior and gastrocnemius muscles contributes to balance improvement with the eyes closed standing on two legs (J. T. Han, Lee, & Lee, 2013).

Deterioration in vestibular function with age has been documented (Enrietto, Jacobson, & Baloh, 1999). An age-related reduction of about 20% of the vestibular hair cells has been reported (Rosenhall, 1973). In addition, there is evidence of a reduction of fibers in the vestibular nerve as people get older (Bergstrom, 1973). Furthermore, age-related reductions were also observed in vestibulo-ocular reflex (VOR) function (Peterka, Black, & Schoenhoff, 1990). These adverse changes in vestibular function as people age appear to affect postural sway. In agreement with this statement, Kerber et al. conducted a study to assess postural stability and the vestibulo-ocular reflex (VOR) in healthy subjects older than 75 years for 9 years follow-up and found a decline of VOR gain over time. Changes in VOR gain were also associated with a decline in the Tinetti gait and balance score (Kerber et al., 2006).

2- <u>Postural sway and brain structural changes and decrease of cognitive function:</u>

Several studies observed a relationship among age-related changes in brain structures, postural stability, and cognitive status (Baloh et al., 2003; Sullivan et al., 2009; Tell et al., 1998). A study conducted by Sullivan et al. found that brain tissue volume reduction and increased volume of supratentorial cerebrospinal fluid (CSF) in the lateral ventricles were associated with increased sway track length in men during static standing conditions (Sullivan et al., 2009). In the same study, the volume of white matter hyperintensities was associated with longer sway track length in women. However, in this study, worse cognitive scores were associated with increased sway track length in women only (Sullivan et al., 2009). Additionally, poor performance on various measures of balance such as the functional reach test and Romberg test have been positively associated with deteriorated brain changes on MRI (Tell et al., 1998). Consistently, white matter abnormalities have been associated with worse dynamic performance on the Tinetti test and worse walking performance (Baloh et al., 2003). Increases in gait speed among elderly people participating in rehabilitation programs depend on the difference in white matter hyperintensities (Nadkarni et al., 2013).

However, these studies do not indicate whether this deterioration in brain structures is the direct cause of poor cognitive status and balance performance or is a marker for other degenerative processes. However, it is suggested that changes in a particular area of the brain is related to specific functional impairment. For instance, one of the brain structural changes is ventricular enlargement which has been found to be associated with gait impairments (Koller, Wilson, Glatt, Huckman, & Fox, 1983; Shprecher, Schwalb, & Kurlan, 2008).

A deterioration in postural sway was found among the older adult population during balance tasks and doing cognitive tasks such as Brooks' spatial memory, backward digit recall in comparison to standing without doing cognitive tasks (Maylor & Wing, 1996). This finding has been observed also between individuals with well-compensated unilateral vestibular loss and healthy age-matched controls (Redfern, Talkowski, Jennings, & Furman, 2004) Also, increasing postural sway has been reported among individuals with ongoing dizziness and disequilibrium when performing balance exercises combined with cognitive tasks (Yardley et al., 2001).

3- Muscle weakness, loss of range of motion, and absence of protective reflexes

Physiological changes in muscles found to be associated with aging includes weakness in lower limb muscles such as the quadriceps muscle (Aniansson et al., 1986; Larsson et al., 1979), hip extensors and flexors (Dean et al., 2004) and ankle dorsiflexors (Lord et al., 1991b). Other changes include a reduction of muscle mass especially after age of 30 yrs. (Borkan, Hults, Gerzof, Robbins, & Silbert, 1983), and decreased number of muscle fibers (Aniansson et al., 1986; Vandervoort & McComas, 1986). As a result, these changes will interfere with older people's ability to perform activities of daily living.

Deterioration in muscle strength associated with an increase in age contributes to poor balance control (Lord et al., 1991b). However, in the Lord et al. study, the association between increased sway and muscle weakness was not detected during a simple balance task (standing on firm surface), but instead, during a more difficult balance task such as standing on foam (Lord et al., 1991b). Moreover, decreased ankle dorsiflexion strength significantly existed among older adults who reported falls compared to non-faller peers (Whipple, Wolfson, & Amerman, 1987). Weakness of hip abductors and adductors is a common issue among elderly people which contributes to poor postural control and higher risk of falling (Moreland, Richardson, Goldsmith, & Clase, 2004).

In summary, previous studies have detailed the effect of age on postural sway. However, the research has been performed during a very limited set of exercise conditions. I will extend this research by examining the effect of age on postural sway in many other diverse exercise conditions that are typically used in balance and vestibular rehabilitation.

2.3.2 Postural sway and different levels of difficulty of balance exercises

The magnitude of postural sway is affected by the hypothetical difficulty of the balance exercise. For example, conditions involving closed eyes, a foam surface, and/or standing on one leg produce more body sway in comparison to those involving open eyes, a firm surface, and standing on two legs, respectively (Gill et al., 2001; Judge, King, Whipple, Clive, & Wolfson, 1995). Postural sway is also worsened in conditions where visual and somatosensory information are distorted when using sway-referenced visual and somatosensory inputs compared to conditions where sensory information is available or even missing completely such as standing with eyes closed (Peterka & Black, 1990; Riley & Clark, 2003). Changing the size of the base of support when the subject stands on a narrow surface will increase postural sway. Danis et al. reported that body sway increased when standing with feet together versus feet apart (Danis, Krebs, Gill-Body, & Sahrmann, 1998).

The effect of different standing conditions, especially sensory conditions, on postural sway has been commonly assessed using the Sensory Organization Test (SOT). The SOT has been found to be a useful tool in detecting balance abnormalities (Cohen et al., 1996). The SOT utilizes a moveable visual enclosure and moveable force plate to record postural sway in six conditions that have different levels of difficulty (Riley & Clark, 2003).

The six conditions of SOT are as follows: condition 1: standing with eyes open on fixed platform surface and visual background; condition 2: standing with eyes closed on fixed platform; condition 3: standing with eyes open on fixed platform surface and sway-referenced visual background; condition 4: standing with eyes open on a sway-referenced platform surface with a fixed visual background; condition 5: standing with eyes closed on sway-referenced platform surface; and condition 6: standing with eyes open on sway-referenced platform surface and with a sway-referenced visual background. Thus the SOT conditions hypothetically increase in difficulty from eyes open to eyes closed, from fixed visual enclosure to sway-referenced visual enclosure, and from a fixed support surface to a sway referenced support surface.

As the SOT conditions become more difficult, moving from condition 1 to condition 6, postural sway increases. In healthy people over the age of 75 years, researchers found that subjects demonstrated more sway during conditions that alter proprioceptive inputs with a moving platform (Judge et al., 1995) compared with conditions with a stable platform. The odds ratio of losing balance when closing the eyes (conditions 2, 5) compared with conditions with eyes open (conditions 1, 4) was 5.7. Whereas, the odds ratio of losing balance with the moving the visual surround (conditions 3, 6) increased to 7.4 compared with conditions with eyes open (conditions 1, 4) (Judge et al., 1995). Moreover, more subjects lost their balance as the SOT progressed from condition 4 to 6 as follows: 25% of the subjects lost their balance in condition 4 (1^{st} trial), whereas 56% lost their balance in condition 5 (1^{st} trial), and 62% lost their balance in condition 6 (1^{st} trial) (Judge et al., 1995).

2.3.2.1 Effect of surface on difficulty of balance exercises

Assessment of postural control during standing on level surface usually does not differentiate between healthy subjects and individuals with balance disorders (Baloh et al., 1998) or young and older adults (Baloh et al., 1998; Liaw et al., 2009; Peterka & Black, 1990). In contrast, using foam in balance assessment is a helpful tool to differentiate between healthy subjects and those who have balance disorders (Fujimoto et al., 2014) and between young and older adults (Baloh et al., 1998). Standing on foam makes the condition more challenging as it reduces the amount of proprioception inputs coming from the sole of the feet and makes the subject rely more on vision and the vestibular system. The effect of using different types of foam on balance measurements has been assessed in different studies (Chia-Cheng Lin, 2014; Patel, Fransson, Lush, & Gomez, 2008; Petit, 2012b). Lin et al. did a test-retest reliability study of two different types of foam (Blue foam - Airex® (density 55 kg/m^3) and Gray foam – NeuroCom (density 60 kg/m^3)) and found that standing on the blue foam (Airex®) with eyes open and closed has a higher reliability (fair to excellent reliability (ICC (3, 1) = 0.41-0.81, $p > 0.05$) compared to standing on the gray foam with eyes open and closed, which has poor to good reliability (ICC (3, 1) = 0.02-0.45, $p > 0.05$) (C. C. Lin et al., 2015). Additionally, compared to standing on firm surface, standing on blue foam revealed a significant difference in three postural sway measures (peak to peak, RMS, and path length), whereas, standing on the gray foam revealed a significant difference in RMS only during eyes closed conditions and in path length during eyes open and closed conditions (C. C. Lin et al., 2015). Another study compared the effect of three different surfaces (firm, closed cell foam (density 55 kg/m^3), and open cell foam (density 32 kg/m^3)) on postural sway measures. The study found that all three surfaces are significantly different from each other in three postural sway measures (A/P sway range, M/L sway range, and Mean velocity) with higher postural sway in standing on the closed cell foam (Petit, 2012b). As a result of this review, I will be using the Airex® foam (density 55 kg/m^3) in this study as it has greater reliability, demonstrates significant differences in more sway measures when compared to NeuroCom one, and significantly higher sway values when compared to another foam of lower density.

2.3.3 Postural sway and interaction between age and difficulty of exercise conditions

Several studies have assessed the interaction between age and difficulty of balance exercise conditions on postural sway. Two studies have assessed postural sway using the SOT with 107 subjects between 16 – 80 years and 214 healthy subjects between 7 – 81 years, and found no age-related effect on postural sway when subjects stood on a firm surface regardless of the visual conditions (Liaw et al., 2009; Peterka & Black, 1990). Paradoxically, whereas one of the studies found no age-related differences in postural sway in condition 3 of the SOT (Liaw et al., 2009), another study found age-related differences in sway in all conditions that involved sway-referenced vision and surface, including condition 3 (Peterka & Black, 1990). Older adults between 60 – 80 years of age demonstrated greater sway compared with younger people 16 – 39 years of age in conditions where they stood on a sway-referenced support (conditions 4, 5, and 6) (Liaw et al., 2009). The average stability score for the elderly group (60-80 yrs.) was significantly different from the younger group (16-39 yrs.) and middle-aged group (40-59 yrs.) (Liaw et al., 2009).

Baloh et al., assessed postural sway of 70 subjects older than 75 and 30 younger subjects using the Chattecx Balance System, which utilizes a movable force plate that induces surface tilts (Baloh et al., 1998). They found that the sway velocity for all conditions combined (firm surface, foam surface, tilting the platform in sagittal direction, and tilting the platform in the lateral direction) was significantly faster in older subjects compared with younger subjects. However, there was no age-related effect on sway during the stable surface conditions. These results are consistent with those of other studies that used the SOT (Liaw et al., 2009; Peterka & Black, 1990). In contrast, sway in older subjects was significantly greater than younger subjects in dynamic conditions especially with standing on platform that tilts in anterior-posterior direction (Baloh et al., 1998).

Although it is clear that postural sway increases when a person loses sensory information through eye closure or standing on an unstable platform, many balance and vestibular rehabilitation exercises involve other challenging conditions. The relative difficulty of these conditions, as determined by the amount of postural sway elicited, has not been determined.

2.4 VESTIBULAR DISORDERS

Approximately 65% of older people who fall suffer from balance disorders (Tinetti, Speechley, & Ginter, 1988) and among those with balance problems, approximately 50% have vestibular disorders (Overstall, Exton-Smith, Imms, & Johnson, 1977). Vestibular hypofunction is defined as a reduction of more than 25% of the caloric response in one ear compared to the other during caloric testing (Jongkees, Maas, & Philipszoon, 1962). Vestibular hypofunction may lead ultimately to increased body sway and risk of falling (Agrawal et al., 2009; Basta et al., 2011; Lee, Kim, Chen, & Sienko, 2012; Stevens, Corso, Finkelstein, & Miller, 2006a).

Two-thirds to three-quarters of older adults who have had hip or wrist fractures were found to have an asymmetrical vestibular function (Kristinsdottir, Jarnlo, & Magnusson, 2000; Kristinsdottir et al., 2001). People with peripheral vestibular dysfunction may restrict their activities and reduce their participation in daily life activities (Giray et al., 2009). Dizziness, imbalance, and visual disturbances are common symptoms of peripheral vestibular hypofunction. Although these symptoms usually diminish within 3 to 6 months post injury (Horak et al., 1992), about 6 million doctors' visits annually in the USA can be attributed to patients experiencing dizziness (Brodovsky & Vnenchak, 2013).

2.4.1 Postural sway and vestibular disorders

The vestibular system is one of the peripheral sensory systems that plays an important role in maintaining balance. The vestibular system in particular helps to coordinate eye movements during head movements and to control balance during upright stance and walking by facilitating contraction of the appropriate lower limb muscles in order to prevent falling.

Vestibular disorders contribute to decreasing postural stability. In a comparison of the postural sway between 70 patients with peripheral and central vestibular disorders or reported dizziness and imbalance for an unknown reason and 70 control subjects both over the age of 75, sway velocity was significantly higher in patients than controls while standing on a platform that was tilting (Baloh et al., 1998). However, there was no significant difference between patients and controls during standing on a firm surface (eyes closed) or foam surface (Baloh et al., 1998). In accordance with the results of the previous study, another study compared 58 patients with vestibular neuritis between 23 – 83 yrs. and 66 healthy matched subjects and found an increase in the postural sway in patients during standing on foam with eyes closed (Fujimoto et al., 2014).

Specific vestibular disorder diagnoses may affect postural control differently. Hong et al. found that people who have vestibular neuritis have significantly more sway during conditions 5 and 6 of the SOT compared with individuals who have Meniere’s disease or migrainous vertigo. Whereas in condition 2, people with migrainous vertigo swayed significantly more than those who had vestibular neuritis (Hong et al., 2013). Individuals with vestibular disorders such as bilateral vestibular loss and cerebellar atrophy tend to have higher sway velocity during static or dynamic standing with eyes closed compared with individuals with a different diagnosis such as a unilateral vestibular loss, a central disorder, or having dizziness and imbalance of unknown cause (Baloh et al., 1998).

2.5 VESTIBULAR REHABILITATION THERAPY (VRT)

Vestibular rehabilitation is a group of exercises designed to stimulate central nervous system compensation through adaptation and habituation approaches in order to reduce symptoms and improve balance function. Vestibular rehabilitation resolves symptoms by enabling the central nervous system to adapt to the asymmetries in peripheral vestibular responses (Brodovsky & Vnenchak, 2013; Horak et al., 1992). Also, habituation exercises have been found to be helpful in training the CNS to recognize correct signals coming from the intact part of the vestibular system as well as other sensory modalities and ignore the false signals through repeating movements that provoke symptoms (Brodovsky & Vnenchak, 2013).

The CNS has the ability to compensate for the conflict in afferent signals coming from the peripheral vestibular system (Helmchen et al., 2011; Shepard & Telian, 1995). The brain's ability to compensate is a result of neuronal plasticity in the cerebellum and the brainstem in response to asymmetries in peripheral vestibular responses (Shepard & Telian, 1995). As a result of this feature, it is suggested that physiotherapists prescribe vestibular exercises (Shepard & Telian, 1995).

Since the early 1940s, vestibular rehabilitation programs were initiated by Cawthorne and Cooksey to enhance vestibular compensation of impaired functions caused by central and/or peripheral disorders (Cawthorne, 1946). Since then, vestibular rehabilitation has been widely accepted with promising results. A recent Cochrane review that included 27 high-quality randomized studies suggested there was moderate to strong evidence that vestibular rehabilitation is safe and effective in treating unilateral peripheral vestibular symptoms (Hillier & McDonnell, 2011).

However, vestibular exercises might not be beneficial with unstable symptoms that occur spontaneously such as with Ménière's disease (B. I. Han, Song, & Kim, 2011). Such symptoms may be resolved with other treatment options such as medications (B. I. Han et al., 2011). In certain cases such as anxiety-related dizziness or migraine-related dizziness a combination of methods might allow for better benefits. Physicians may prescribe medication to decrease dizziness along with having the patient attend a trial of vestibular rehabilitation (Furman, Cass, & Whitney, 2010).

Compared with a generic exercise program, customized vestibular rehabilitation programs based on the physiotherapist examination have been found to decrease the symptoms of vestibular dysfunction and improve the patients' balance for those who sustained chronic vestibular loss symptoms (Giray et al., 2009; Shepard & Telian, 1995). Shepard and Telian studied 35 patients 18 to 69 years old with unilateral peripheral or central vestibular pathology and compared the results of customized versus generic vestibular rehabilitation programs. At the completion of the study, 85% of the patients in the customized group reported full recovery of symptoms versus 65% of the patients in the generic group (Shepard & Telian, 1995).

A study was conducted to find out which vestibular rehabilitation technique was more effective in the treatment of patients with unilateral peripheral vestibular disorders. Computerized dynamic posturography (CDP) and optokinetic stimulation (OKN) were compared (12 patients in each group). After the evaluation, they found that both groups had significantly improved. In the CDP group, greater improvement occurred in patients who performed worse during conditions where subjects relied more on vision and vestibular inputs, whereas in the OKN group, greater improvement occurred in patients with visual preference (Rossi-Izquierdo M, 2011). Vestibular rehabilitation for bilateral vestibular patients has been found to be more effective in reducing symptoms and increasing stability when it was customized for the patient's deficits (Shepard & Telian, 1995).

Vestibular rehabilitation exercises can be divided into two main categories which are gaze stabilization and balance exercises such as walking and standing (Whitney & Sparto, 2011). Gaze stabilization exercises are meant to reduce dizziness by having the patient move his/her head in different directions while vision remains fixed on a target in front of the patient. A variety of exercises can be prescribed by changing the speed and direction of the head movement (yaw, pitch, roll), standing surface (level, foam, etc.), base of support (feet apart, feet together, semi tandem, etc.), and change from sitting to standing and then walking position (Brodovsky & Vnenchak, 2013; Herdman & Clendaniel, 2014; Vereeck, Wuyts, Truijen, De Valck, & Van de Heyning, 2008; Whitney & Sparto, 2011; Yardley et al., 2004). A recent clinical practice guideline summarized the evidence for gaze stabilization exercises for treatment of peripheral vestibular hypofunction (Hall et al., 2016). Jung et al. found that gaze stabilization exercises are helpful in decreasing dizziness in elderly subjects. The prescribed exercises included turning the head in horizontal or vertical plane with different speeds and were done in sitting or walking position with eyes open or closed (Jung, Kim, Chung, Woo, & Rhee, 2009). Similarly, Herdman et al. used vestibular adaptation exercises with patients after acoustic neuroma resection and found improvement in peak-to-peak AP sway. The exercises included in this study were turning head right and left or up and down while standing or sitting (Herdman, Clendaniel, Mattox, Holliday, & Niparko, 1995).

On the other hand, balance exercises in walking and standing are designed for subjects who have difficulty in controlling their posture. Different exercises can be created by modifying the size of base of support, altering the visual inputs, changing surface compliance, or performing in different postural positions such as sitting or standing. A randomized control study by Vereeck et al. incorporated gaze stability and balance exercises for patients after acoustic neuroma resection (young and older) and general instructions for the control group (young and older). Older adults in the experimental group showed significant improvements in most of the balance tests such as standing balance, Timed Up and Go test, tandem gait, and Dynamic Gait Index (DGI) compared to older adults in control group. In contrast, no significant difference was found between younger adult groups (Vereeck et al., 2008).

A number of studies have developed exercise progression patterns which contributed to decreasing symptoms and increasing function for persons with vestibular disorders. In a randomized study conducted on 13 patients with bilateral vestibular hypofunction, researchers used their clinical experience to develop a progression of eye and head movement exercises for the treatment group whereas the control group received placebo exercises (Herdman, Hall, Schubert, Das, & Tusa, 2007). First, they increased the number of repetitions of the exercises during the day and the duration of exercise. Then, they placed the visual target in more complex visual backgrounds. These changes were progressed so that they did not evoke symptomatic complaints. The treatment group gained better dynamic visual acuity and decreased symptoms compared to the placebo exercise group (Herdman et al., 2007).

Alsalaheen et al. did a retrospective study of 104 patients who had been diagnosed with concussion and received vestibular rehabilitation exercises (Alsalaheen et al., 2013). Their aim was to describe the exercises given by the physical therapist and how they were progressed to make them more challenging. Exercises were classified into five types as follows: eye-head coordination, sitting balance, standing static balance, standing dynamic balance, and ambulation. These exercises were progressed by modifying conditions within each exercise category to make them more challenging. For example, the performance of the VORx1 exercise was progressed by having subjects perform the exercises in sitting, then standing with feet apart, and then standing with feet together, and then standing with feet semi-tandem. The exercise progression conditions included changes in posture position, surface type, base of support, trunk position, arm position, head movement direction, direction of whole body movement, visual input, and a cognitive dual task.

In a case report study, Gill-body et al. documented a vestibular rehabilitation program for 2 older patients with unilateral and bilateral vestibular hypofunction. The program has included a number of balance exercises that were distributed over a period of 8 weeks into three phases with various levels of difficulties from easier to harder respectively. The first phase extended for two weeks and included static standing on firm surface with eyes open and closed and feet together with arms outstretched and a book on head, walking with narrowed base of support and eyes open, marching in place slowly with eyes open, and active head movement in yaw, pitch, and roll planes. In the second phase, which extended for 4 weeks, exercises were progressed to static standing in semi-tandem stance with eyes open and closed and arms close to body with a book on head, static standing on foam surface with eyes open and book on head, walking with normal and narrow base of support with eyes open and a book on head, and active head movement in yaw, pitch, and roll planes. In the final phase, which lasted for two weeks, exercises were progressed to static standing on foam surface with eyes closed and with and without a book on head, walking with narrowed base of support with eyes closed and with and without a book on head, walking with normal base of support with fast head movements, marching in place slowly with eyes open and closed and with and without a book on head, and active head movements in yaw, pitch, and roll planes (Gill-Body, Krebs, Parker, & Riley, 1994).

One of the potential limitations of vestibular rehabilitation therapy is that real time feedback is not usually provided during the home based exercises (Martin G., et al, 2012). It has been found that providing biofeedback based treatment based on measuring the displacement of body sway helps patients who have balance disorders to restore balance and reduce falls (Wall, 2010).

Biofeedback technologies have been used along with vestibular rehabilitation to enhance the effect of physical therapy interventions. Biofeedback has been used to take place of vestibular system in complete loss or augment with partial loss. Different ways of providing feedback include auditory, visual, vibrotactile, and tongue electrotactile feedback.

Auditory feedback helped patients with bilateral vestibular loss to control their posture during standing and walking tasks (Dozza et al., 2005; Hegeman, Honegger, Kupper, & Allum, 2005). Dozza et al. did another study using auditory feedback with bilateral vestibular loss and healthy subjects and found a significant reduction of COP-RMS in three different standing conditions (eyes closed, eyes open on a foam, eyes closed on a foam) (Dozza, Horak, & Chiari, 2007). Similarly, Chiari et al. reported a significant reduction in COP-RMS and mean velocity in the same conditions with healthy subjects (Chiari et al., 2005).

People who have vestibular dysfunction often complain of difficulty walking in circumstances where there are many visual distractions (Whitney et al., 2006). As a result, some studies support the use of virtual reality as a part of vestibular rehabilitation as it provides visual and auditory feedback in different levels of challenging scenes (Meldrum, Herdman, et al., 2012). Virtual reality helped patients with Ménière's disease in reducing their dizziness symptoms and increase limit of stability (Garcia et al., 2013). Pavlou stated in her review those vestibular rehabilitation programs that incorporate optokinetic stimulation are more beneficial than programs that don’t include optokinetic stimulation (Pavlou, 2010).

Vibrotactile biofeedback (VTF) has been shown to reduce trunk sway in many studies over the last decade (Dozza, Wall, Peterka, Chiari, & Horak, 2007; Kentala, Vivas, & Wall, 2003; Sienko, Balkwill, Oddsson, & Wall, 2008; Sienko, Vichare, Balkwill, & Wall, 2010; Wall & Kentala, 2005). After training older adults with this technology, one study found that it helped older adults to improve their score in Dynamic Gait Index (DGI) which is considered a fall risk indicator (Wall, Wrisley, & Statler, 2009) while another study reported a reduction in trunk tilt measurements in older adults (Haggerty, Jiang, Galecki, & Sienko, 2012). As far as using VTF with patients is concerned, a study found that VTF reduced lateral trunk tilt in patients with vestibulopathies during some walking tasks (Horak, Dozza, Peterka, Chiari, & Wall, 2009; Sienko, Balkwill, Oddsson, & Wall, 2013).

Several studies combined different types of feedback together in attempt to increase the effect of the intervention. A study used multi-modal biofeedback including vibrotactile, visual, auditory feedback which were provided to young and older adults during standing and gait tasks. The vibrotactile feedback activation threshold was the smallest, followed by auditory feedback and lastly by visual feedback. A couple of trunk tilt measures reduced significantly in all subjects compared to a control group during standing as well as gait tasks (Davis et al., 2010). Another study combined visual and auditory feedback during balance exercises for older adults and found an improvement in postural sway measures and some functional tests including Timed Up and Go (Schwenk et al., 2014).

2.6 CLINICAL APPLICATIONS FOR THIS STUDY

According to the American College of Sports Medicine (ACSM), there is a lack of studies that show the appropriate progression of balance exercises for older adults who suffer from frequent falls (Pescatello & American College of Sports Medicine., 2014). In addition, Farlie et al (2013) performed a systematic review of balance intervention studies and found that there was no description of the intensity of balance exercises (Farlie, Robins, Keating, Molloy, & Haines, 2013). However, the ACSM recommends reducing the base of support (e.g. changing from standing feet apart to feet together, to semi tandem, to tandem, to single leg stance) and sensory inputs (e.g. changing from eyes open to eyes closed) (Pescatello & American College of Sports Medicine., 2014).

Several groups have attempted to develop a way to grade the intensity of balance exercises. Muehlbauer et al. did an experiment to assess the relative difficulty of 12 balance exercises and to set a progression sequence. They had young subjects stand in 4 different bases of support (feet apart, semi tandem, tandem, and single leg) on either a firm surface with eyes open, foam surface with eyes open, or firm surface with eyes closed. COP displacement increased gradually from exercises done on the firm surface with eyes open, to the foam surface with eyes open, to firm surface with eyes closed. In addition, the COP displacement increased as the base of support changed from feet apart, to semi tandem, to tandem and finally to single leg stance. Furthermore, they came up with a sequence of all 12 exercises, starting from the exercise that produced the least COP displacement (standing on firm surface and feet apart with eyes open) to the exercise that produced the most COP displacement (standing on firm surface and single leg stance with eyes closed) (Muehlbauer, Roth, Bopp, & Granacher, 2012).

Farlie et al. did an observational study to explore the verbal and nonverbal responses during three exercises of different levels of difficulty so that they could develop an instrument that measures the intensity of balance difficulty (Farlie, Molloy, Keating, & Haines, 2016). They found that as the difficulty of the exercises increased, the time delay before commencing the exercise increased as well as the number of comments that subjects made before, during, and after exercises increased accordingly with the increased difficulty of the exercise. Additionally, they visually observed the physical responses and found that postural sway and postural reactions such as stepping and reaching increased as the exercise difficulty increased. Furthermore, at the end of each exercise, they asked their subjects to describe their perception of how difficult they found the exercise. The subjects' perception seemed to correlate positively with the exercise intensity (Farlie et al., 2016).

For aerobic and resistance exercises, there are well defined rules for how to determine the initial prescription for exercise intensity as well as how to progress the intensity level. According to American College of Sports and Medicine (ACSM) guidelines, initial intensity prescription of aerobic exercise is 40-60% of the heart rate reserve, which is considered a moderate intensity and may progressed to a vigorous intensity (60-85%) during endurance training and general aerobic exercises (Pescatello & American College of Sports Medicine., 2014). The prescribed intensity may vary depending on the fitness level and goals of the trainee, and whether the trainee has chronic diseases or not (Pescatello & American College of Sports Medicine., 2014). Similarly, the intensity of resistance training is defined as a percentage of one repetition maximum (1 RM), which is the maximum weight that can be lifted for one time throughout the full range of motion. The ACSM recommends different intensity ranges depending on the type of exercise, whether it is muscular strength, endurance, or hypertrophy, and also the intensity depends on the level of the trainee (beginners, intermediate, or advanced). For instance, to increase muscular strength, it is recommended to prescribe the intensity between 60-70% of 1 RM for novice and intermediate and between 80-100% for advanced trainees. For muscular endurance, the ACSM recommends to prescribe the intensity of the resistance exercises lower than 70% of 1 RM, whereas, it is suggested for novice and intermediate trainees to left weights of intensity between 70-85% of 1 RM and 70-100% for advanced trainees in order to increase muscle mass (Pescatello & American College of Sports Medicine., 2014).

Furthermore, the rating of perceived exertion for aerobic and resistance exercises was developed to assist in determining how trainees perceive the intensity of activity in cases where the heart rate reserve or the maximum weight that can be lifted cannot be measured, due to medical conditions (e.g. heart failure), using a medication that affects the heart rate in response to physical effort, or lack of medical equipment to measure the event of interest (Robertson et al., 2004; Robertson et al., 2003; Utter et al., 2004). During training programs, rating of perceived exertion scales help to monitor the intensity of the activity and provide healthcare providers with feedback of how hard their clients' feel like they are exercising as well as if their clients are ready to progress to the next level of intensity.

During the performance of balance exercises, measuring or visually observing the amount of sway is a common way of assessing the difficulty of exercises. However, many clinics don't have the capability to measure sway or interpret its results. In addition, visual observation is an imprecise tool, and evidence of inter-rater reliability is not established. Therefore, clinicians can use the rating of perceived difficulty scales for determining the intensity of balance exercises and progress them in cases when measuring sway is not an option. Additionally, ratings of perceived difficulty can be used for home-based balance exercise training to provide feedback to the physical therapist of how well the exercises met the targeted intensity.

In this study we measured the trunk tilt and center of pressure induced during common static standing balance exercises, and asked subjects to rate their perceived difficulty of each exercise in order to establish a standard way of assessing the level of difficulty of the exercises (i.e. intensity). These measurements may facilitate better treatment progression algorithms used in practice and research. Several measures of the postural sway data (i.e. 90% range and IQR) can be used for different purposes: such as setting the thresholds for feedback delivered by sensory augmentation technologies. For example, the IQR could be used to set the first threshold when vibrotactile feedback would be activated, and the 90% range could trigger an even stronger feedback to alert the subject that a postural stabilizing correction needed to be activated imminently. The purpose of this study is to determine the relative difficulty of a wide variety of static standing exercises commonly performed in balance and vestibular rehabilitation, and validate common rubrics for treatment progression by recording postural sway measures (trunk tilt and center of pressure) and perceived difficulty. In addition, the effect of age on postural and perceptual measures will also be examined over a wide spectrum of ages from 18 to 85 years old as well as recruiting individuals with vestibular disorders to understand the effect of having vestibular disorders on postural sway measures and the perceived difficulty.

3.0 METHODS

3.1 EXPERIMENTAL DESIGN

This research consists of four aims. For aims 1 and 2, a cross-sectional study was done to determine test-retest reliability of the subjects' performance of static standing balance exercises, within and between two visits occurring one week apart and to establish concurrent validity of two scales of rating of perceived difficulty of balance exercises by comparing the scales with quantitative postural sway measures. For aims 3 and 4, an experimental study using a within-subjects and between-groups design was done to determine the effect of age, having a vestibular disorder, and different exercise conditions on balance.

All potential research participants came in for a screening visit. The eligible subjects were asked to come back for testing during a 2nd visit, and only healthy subjects were asked to come for a 3rd visit one week later. For Aim 3, the independent variables are the age groups (4 levels) and the exercise conditions (i.e. surface - 2 levels; visual input - 2 levels; base of support - 2 levels; and head movement - 3 levels). The different levels of exercise conditions are shown in Table 3-1. These conditions were tested in a full factorial design which make a total of 24 exercises as shown in Table 3-2. For Aim 4, the independent variables are presence of vestibular disorder (yes or no) and the same exercise conditions as above except pitch movement, which make a total of 16 exercises. The dependent variables are trunk tilt, center of pressure, and rating of perceived difficulty.

Table 3-1: Chosen conditions of static standing exercises

Exercise category	Surface	Visual input	Base of support	Head movement
Static standing	Level surface Foam surface	Eyes open Eyes closed	Feet apart Semi-tandem	Head still Yaw Pitch

Table 3-2: The balance and vestibular exercises

Exercise number	Surface	Visual input	Base of support	Head movement
1	Firm	Eyes open	Feet apart	Head still
2	Firm	Eyes open	Feet apart	Yaw
3	Firm	Eyes open	Feet apart	Pitch
4	Firm	Eyes open	Semi-tandem	Head still
5	Firm	Eyes open	Semi-tandem	Yaw
6	Firm	Eyes open	Semi-tandem	Pitch
7	Firm	Eyes closed	Feet apart	Head still
8	Firm	Eyes closed	Feet apart	Yaw
9	Firm	Eyes closed	Feet apart	Pitch
10	Firm	Eyes closed	Semi-tandem	Head still
11	Firm	Eyes closed	Semi-tandem	Yaw
12	Firm	Eyes closed	Semi-tandem	Pitch
13	Foam	Eyes open	Feet apart	Head still
14	Foam	Eyes open	Feet apart	Yaw
15	Foam	Eyes open	Feet apart	Pitch
16	Foam	Eyes open	Semi-tandem	Head still
17	Foam	Eyes open	Semi-tandem	Yaw
18	Foam	Eyes open	Semi-tandem	Pitch
19	Foam	Eyes closed	Feet apart	Head still
20	Foam	Eyes closed	Feet apart	Yaw
21	Foam	Eyes closed	Feet apart	Pitch
22	Foam	Eyes closed	Semi-tandem	Head still
23	Foam	Eyes closed	Semi-tandem	Yaw
24	Foam	Eyes closed	Semi-tandem	Pitch

3.2 PARTICIPANTS

Sixty-two healthy subjects who were independently participating in daily activities, and were between the ages of 18 and 85 years old (31 females and 31 males, mean age 55 ± 20 years) participated in this study. Study participants were distributed into four groups as follow: young (18-44 years old; n = 17), middle aged (45-59 years old; n = 15), old (60-74 years old; n = 15), and very old (75-85 years old; n = 15). Age divisions were developed based on age-related changes in the postural sway found in several studies (Abrahamova & Hlavacka, 2008; Baloh et al., 1998; Era et al., 2006; Gill et al., 2001; Liaw et al., 2009; Peterka & Black, 1990; Rine et al., 2013; Rosenhall & Rubin, 1975; Sheldon, 1963).

Participants with vestibular disorders were recruited from the Balance Disorders Clinic of the University of Pittsburgh Medical Center. We attempted to enroll as many individuals with confirmed vestibular disorders as possible to understand the influence of vestibular disorders on postural sway. A confirmed diagnosis of peripheral or central vestibular disorder was made by a neurotologist based on caloric testing, rotational chair testing, and vestibular evoked myogenic potentials and history. Patients were gender and age (±3 years of age) matched with healthy subjects in a ratio of 1:2. The matched healthy subjects' data was used from a larger study.

Healthy subjects and patients were between the age of 18 and 85 years old and participating in daily activities independently. Subjects were excluded if they were unable to stand for 3 minutes without rest; had distal sensory loss (unable to complete the Romberg test for 30 seconds and unable to feel a pressure of 4.31 g monofilament applied on two different parts of each foot with eyes closed), had visual acuity worse than 20/40, had a diagnosis of benign paroxysmal positional vertigo (BPPV) (positive Dix–Hallpike test or positive supine roll test), had a history of neurological or orthopedic disorders; used an assistive device for ambulation;

were pregnant; had excessive weight (BMI > 35); had cognitive impairment (≤ 25 points on the Montreal Cognitive Assessment). Additionally, healthy subjects were excluded if they had a history of falling 2 times or more within the last 12 months doing activities of daily living; or had a peripheral vestibular disorder (positive head thrust test).

This study was approved by the Institutional Review Board in University of Pittsburgh. All subjects provided a written informed consent prior to participating in the study.

3.3 SAMPLE SIZE JUSTIFICATION

The sample size was calculated using the software G Power 3.1.7 (Faul, Erdfelder, Lang, & Buchner, 2007) based on models that tested for the main effect of age, and main effects of the modifying factors. The most conservative effect size was found in a study that examined the difference in postural sway between young and older subjects performing static balance exercises (standing with eyes open or open in the dark on fixed or movable surfaces) was 0.6 (C. C. Lin, 2014). Based on a pilot study that I did prior to this study, the most conservative effect size for the modifying factors was 0.2. We did not have an estimate for the effect size for the interaction between age and modifying factors, so we used the most conservative effect size of 0.2. As a result, we found that sample size in each group should be 15 subjects at an alpha of 0.05 and a power of 0.80.

Table 3-3: Effect sizes

Independent variables	Effect size
Age	0.6
Surface	1.4
Visual input	0.38
Base of support	0.73
Head movement (Head still vs. Yaw)	0.35
Head movement (Yaw vs. Pitch)	0.2
Head movement (Head still vs. Pitch)	0.56

3.4 PREPARATION FOR THE STUDY

In preparation for this study, several factors were used to determine the choice of static standing balance exercises. The factors were chosen based on review of vestibular rehabilitation literature, consultation from physical therapists, conduction of a pilot study, and consideration of the amount of time that the chosen exercises will take.

Upon reviewing several studies in the vestibular rehabilitation literature, static standing balance exercises were chosen because they are one of the most commonly prescribed exercises, and the fact that the exercises can be done in a clinical setting and at home. Standing on a level surface and foam are the most common surface conditions prescribed in several studies as part of balance training programs (Alsalaheen et al., 2013; Brodovsky & Vnenchak, 2013; Gill-Body et al., 1994; Gill et al., 2001; Meldrum, Glennon, Herdman, Murray, & McConn-Walsh, 2012; Whitney & Sparto, 2011). In contrast, standing on a ramp (Vereeck et al., 2008) or sway referenced platform are less commonly reported and patients are not able to do this at home. In the same way, exercises with eyes open and closed are the most prescribed visual conditions (Alsalaheen et al., 2013; Brodovsky & Vnenchak, 2013; Gill-Body et al., 1994; Gill et al., 2001;

Jung et al., 2009; Vereeck et al., 2008; Whitney & Sparto, 2011; Yardley et al., 2004) followed by complex patterns (Brodovsky & Vnenchak, 2013; Vereeck et al., 2008), whereas the visual sway referenced exercise is the least commonly reported one. As far as base of support is concerned, five base of support stances (feet apart, feet together, semi-tandem Romberg, tandem Romberg, and single leg stance) are roughly reported in the same amount (Alsalaheen et al., 2013; Gill-Body et al., 1994; Gill et al., 2001; Meldrum, Glennon, et al., 2012; Vereeck et al., 2008; Whitney & Sparto, 2011). The choice of which base of support conditions were selected will be discussed later in the preliminary data section. Standing with head still and moving the head in yaw or pitch planes are widely reported in studies related to vestibular rehabilitation (Alsalaheen et al., 2013; Gill et al., 2001; Herdman et al., 1995; Jung et al., 2009; Meldrum, Glennon, et al., 2012; Vereeck et al., 2008; Whitney & Sparto, 2011; Yardley et al., 2004), whereas moving the head in roll plane is not commonly reported.

In addition to reviewing several studies in the vestibular rehabilitation literature, four physical therapists who specialized in vestibular rehabilitation and have at least 9 years of experience were consulted to determine which common exercises that they prescribe for their patients, but are not included in vestibular rehabilitation research. The physical therapists stated that they use provocative visual motion (such as a disco ball) or have patients to look at a checkerboard pattern.

The other decisions about the experimental design were based on a pilot study that I conducted.

3.5 PRELIMINARY DATA

After making a list of 64 exercises, a pilot study was conducted with 3 healthy young adult subjects (29 y/o, 28 y/o and 26 y/o) who performed all exercises to determine which exercises should be eliminated. The findings of this pilot study were as follows (Table 3-4). The effect of foam and eyes closed conditions was greater than the effect of standing on level surface and eyes open in all postural sway measurements. The effect of standing in semi-tandem stance is greater than the effect of standing feet apart in all postural sway measurements except A/P RMS and 90% range of center of pressure. As far as head movement effect is concerned, moving the head in the pitch plane showed higher sway values in all postural sway measurements except 90% range of M/L direction of trunk tilt followed by yaw movement and then head still (Table 3-4). A test of normality using the Kolmogorov-Smirnov test showed that only one trial (A/P trunk tilt) out of 141 trials was normally distributed.

Table 3-4: Descriptive data from the pilot study

Surface	Level, Mean (SD)		Foam, Mean (SD)
Tilt_AP_range50	0.7 (0.4)		1.5 (0.6)
Tilt_AP_range90	1.7 (1.2)		3.7 (1.6)
Tilt_ML_range50	0.4 (0.4)		0.7 (0.3)
Tilt_ML_range90	0.8 (0.6)		1.9 (1.0)
COP_AP_rms	0.6 (0.4)		1.8 (0.6)
COP_AP_range90	1.9 (1.2)		5.9 (2.1)
COP_ML_rms	0.5 (0.5)		1.1 (0.5)
COP_ML_range90	1.9 (1.7)		3.7 (1.7)
Visual input	Eyes open, Mean (SD)		Eyes closed, Mean (SD)
Tilt_AP_range50	1.0 (0.7)		1.2 (0.6)
Tilt_AP_range90	2.4 (1.6)		3.0 (1.8)
Tilt_ML_range50	0.4 (0.3)		0.6 (0.5)
Tilt_ML_range90	1.1 (0.8)		1.6 (1.1)
COP_AP_rms	1.0 (0.7)		1.3 (0.9)
COP_AP_range90	3.4 (2.3)		4.3 (2.8)
COP_ML_rms	0.7 (0.5)		1.0 (0.6)
COP_ML_range90	2.5 (1.8)		3.2 (2.0)
Base of support	Feet apart, Mean (SD)		Semi-tandem, Mean (SD)
Tilt_AP_range50	1.1 (0.7)		1.1 (0.6)
Tilt_AP_range90	2.5 (1.4)		3.0 (2.0)
Tilt_ML_range50	0.3 (0.2)		0.8 (0.5)
Tilt_ML_range90	0.9 (0.6)		1.9 (1.1)
COP_AP_rms	1.2 (0.9)		1.1 (0.6)
COP_AP_range90	3.9 (3.1)		3.8 (2.0)
COP_ML_rms	0.5 (0.4)		1.2 (0.5)
COP_ML_range90	1.6 (1.2)		4.1 (1.7)
Head movement	Head still, Mean (SD)	Yaw, Mean (SD)	Pitch, Mean (SD)
Tilt_AP_range50	1.0 (0.6)	0.9 (0.5)	1.4 (0.7)
Tilt_AP_range90	2.1 (1.0)	2.6 (1.6)	3.4 (2.2)
Tilt_ML_range50	0.4 (0.3)	0.6 (0.3)	0.6 (0.5)
Tilt_ML_range90	1.0 (0.7)	1.6 (1.2)	1.5 (1.0)
COP_AP_rms	1.0 (0.7)	1.2 (0.7)	1.4 (0.8)
COP_AP_range90	3.3 (2.4)	3.9 (2.5)	4.5 (2.7)
COP_ML_rms	0.7 (0.4)	0.9 (0.7)	1.0 (0.6)
COP_ML_range90	2.2 (1.5)	3.1 (2.2)	3.2 (1.9)

Conducting the pilot study helped to make a couple of other decisions about which conditions to test. The first decision involved the amount of time for the experiment. The choice of exercises was limited to a number of exercises that can be done within a time frame of 2 hours, which is considered a reasonable amount of time for 1 visit. After taking into account the fact that each exercise is done twice for 35 seconds each plus 1-minute rest break after every 3 exercises and the consenting and screening process is taking place during the 1st visit. I found that 24 exercises can fit within 2 hours' period.

Next, after determining that I could only have two base of support conditions, I decided to eliminate the tandem and single leg stance conditions because two of the subjects could not maintain 8 out of 12 of the tandem Romberg conditions and 2 out of 3 of the single leg stance conditions. However, they lost their balance on only 1 out of 12 of the feet together and semi-tandem Romberg conditions. As far as the remaining conditions, I will include the easiest condition (feet apart) and the most challenging condition (semi-tandem) (see Table 3-5), based on the results of the postural measurements in the M/L direction.

Table 3-5: The magnitude of postural measurements of different base of support conditions

Base of support	Feet apart	Feet together	Semi-tandem
Measurements	Mean (SD)	Mean (SD)	Mean (SD)
Tilt_AP_range50	1.1 (0.7)	1.1 (0.6)	1.1 (0.6)
Tilt_AP_range90	2.5 (1.4)	2.7 (1.5)	3.0 (2.0)
Tilt_ML_range50	0.3 (0.2)	0.6 (0.3)	0.8 (0.5)
Tilt_ML_range90	0.9 (0.6)	1.5 (0.7)	1.9 (1.1)
COP_AP_rms	1.2 (0.9)	1.1 (0.5)	1.1 (0.6)
COP_AP_range90	3.9 (3.1)	3.6 (1.8)	3.8 (2.0)
COP_ML_rms	0.5 (0.4)	1.1 (0.5)	1.2 (0.5)
COP_ML_range90	1.6 (1.2)	3.6 (1.9)	4.1 (1.7)

3.6 INSTRUMENTATION

During the performance of the exercises in static standing, subjects stood on a force platform (NeuroTest, NeuroCom, Inc., Clackamas, OR) that measured ground reaction forces at a sampling rate of 100 Hz. An inertial measurement unit (IMU, Xsense Technologies B.V., Enschede, The Netherlands) was mounted on each subject's lower back at the level of iliac crest (L4) to measure trunk angular displacement and velocity from vertical and linear acceleration in AP and ML directions at a sampling rate of 100 Hz. The IMU uses a combination of accelerometers, gyroscopes, and a magnetometer. The signals from the force plate and the inertial measurement unit were synced by starting both devices at the same time manually.

3.7 EXPERIMENTAL PROCEDURE

3.7.1 Screening visit

Consented subjects underwent screening tests done by physical therapist to ensure that they were eligible for the study. Screening tests included:

- Romberg test: subjects stand with their feet together, arms at their sides, and eyes closed for 30 sec. The test is stopped and subject excluded if the subject changes his/her feet or arms starting position or opens his/her eyes (Horak, 1987).

- Monofilament test: subjects close their eyes during this test. The examiner touches two different sites of the subject’s foot (plantar surface and medial side of the heel) three times with monofilament. Subjects will be excluded if they cannot feel the 4.31 monofilament (Holewski, Stess, Graf, & Grunfeld, 1988).

- Visual acuity test: is used to measure how well the subject can see using a standardized chart held in a distance of 20 feet away from the subject. Subjects included in this study has a visual acuity measurment of 20/40 or higher (Brien Holden, 2008; Muhammad, Alhassan, & Umar, 2015; World-Health-Organization, 2003) .

- Montreal Cognitive Assessment - Version 3 (MOCA): The purpose of this test is to assess the cognitive ability in different domains such as visuospatial ability, naming task, orientation to time and place, and memory. The MOCA has been validated in detecting Mild Cognitive Impairment with sensitivity and specificity of 90% and 87% respectively (Nasreddine et al., 2005). The examiner will administer the test and subjects will be excluded if they score ≤ 25 points out of 30 on the test (Nasreddine et al., 2005).

- Dix–Hallpike Test: is a diagnostic maneuver to confirm the diagnosis of Benign Paroxysmal Positional Vertigo (BPPV) in the posterior semicircular canal. The Dix-Hallpike maneuver is performed on an examination table by turning the patient’s head 45° to one side and then moving the patient rapidly from sitting to supine position with the head extended over the end of the table about 30 degrees. This position should be held for about 20 seconds. In BPPV patients, clinicians should see nystagmus toward the lower ear (Dix & Hallpike, 1952).

- Supine Roll Test: The Supine Roll Test is used to evaluate for horizontal semicircular canal BPPV. The supine roll test typically starts from a straight supine position with the head in a neutral position. The head is quickly rolled 90 degrees to one side with observation of the patient’s eyes for nystagmus. The patient is asked to report any vertigo, and is then rotated back to a neutral position. Then the head is turned quickly 90 degrees to the opposite side with observation for nystagmus and the patient is asked to report any vertigo. The side with the greatest prominent horizontal nystagmus is mostly expected to be the affected side (Herdman & Tusa, 2007).

Moreover, only healthy subjects will undergo one additional screening test:

- The Head Thrust Test (HTT): The HTT is used to assess the Vestibulo-Ocular Reflex (VOR) which is produced by the horizontal semicircular canal (HSCC). The examiner will grasp and flex the subject’s head into 30 degrees of cervical flexion and ask the subject to fix his/her eyes on a target. The examiner will then generate unpredictable rapid head movements while monitoring the subject’s eyes. The presence of a corrective saccade is a positive sign that indicates the presence of peripheral vestibular hypofunction on the side where the head was rotated. The Head Thrust Test has a good sensitivity (71% and 84%) in identifying people with unilateral and bilateral vestibular hypofunction respectively. Also, the Head Thrust Test has a good specificity (82%) in identifying people with unilateral and bilateral vestibular hypofunction (Schubert, Tusa, Grine, & Herdman, 2004).

Eligible subjects who met the study criteria completed the Activities-specific Balance Confidence Scale (ABC) questionnaire, Functional Gait Assessment (FGA), and their gait speed was measured prior to experiment in order to better describe the participants. Moreover, people with vestibular disorders completed the Dizziness Handicap Inventory (DHI) and self-report of dizziness on visual analog scale.

First, subjects completed an Activities-specific Balance Confidence Scale (ABC) questionnaire (Powell & Myers, 1995). The purpose of the questionnaire is to record the subject's confidence level in participating in 16 daily activities without losing balance or feeling unstable. This questionnaire is a self-report measure with scores ranging from 0-100, where 0 indicates that the subject doesn't feel confident whereas 100 indicates that the subject is highly confident. This questionnaire has excellent test-retest reliability ($r = 0.92$, $p < 0.001$) assessed in the elderly population (Powell & Myers, 1995).

Second, subjects performed the Functional Gait Assessment (FGA) test to assess their postural control during 10 walking tasks (Wrisley, Marchetti, Kuharsky, & Whitney, 2004). The FGA is a 10-item physical test with a score ranging from 0-30, where 0 indicates worse postural control whereas 30 indicates best postural control. The FGA has excellent test-retest reliability (ICC = 0.83) assessed in patients with vestibular disorders (Wrisley et al., 2004).

Third, all subjects' gait speed was measured over 6 meters (Steffen, Hacker, & Mollinger, 2002). Subjects were instructed to walk at their comfortable speed for 10 meters; their speed during the middle 6 meters was measured to avoid the effect of acceleration and deceleration. Data was collected over three trials and the average of the three trials was calculated.

Fourth, patients with vestibular disorders completed the Dizziness Handicap Inventory (DHI) to measure the impact of dizziness on their daily life in three domains: functional, emotional, and physical (Jacobson & Newman, 1990). The DHI has 25 questions with a score ranging from 0-100, where 0 indicates no perceived handicap due to dizziness whereas 100 means the greatest perceived handicap due to dizziness. The DHI has excellent test-retest reliability ($r = 0.97$, $p < 0.0001$) assessed in patients with vestibular dysfunction (Jacobson & Newman, 1990).

Finally, patients with vestibular disorders assessed their perceived level of dizziness on a visual analog scale (Hall & Herdman, 2006; Toupet, Ferrary, & Grayeli, 2011). Visual analog scale of dizziness is a 10-cm vertical line with the lower end labeled as no dizziness at all whereas the upper end labeled with the following phrase “as bad as can be” (Figure 3-1). Subjects will be asked to indicate their dizziness level by drawing a mark along the vertical line. The distance from the lower end of the vertical line to the mark will be measured and counted as the nearest millimeter (Hall & Herdman, 2006; Toupet et al., 2011).

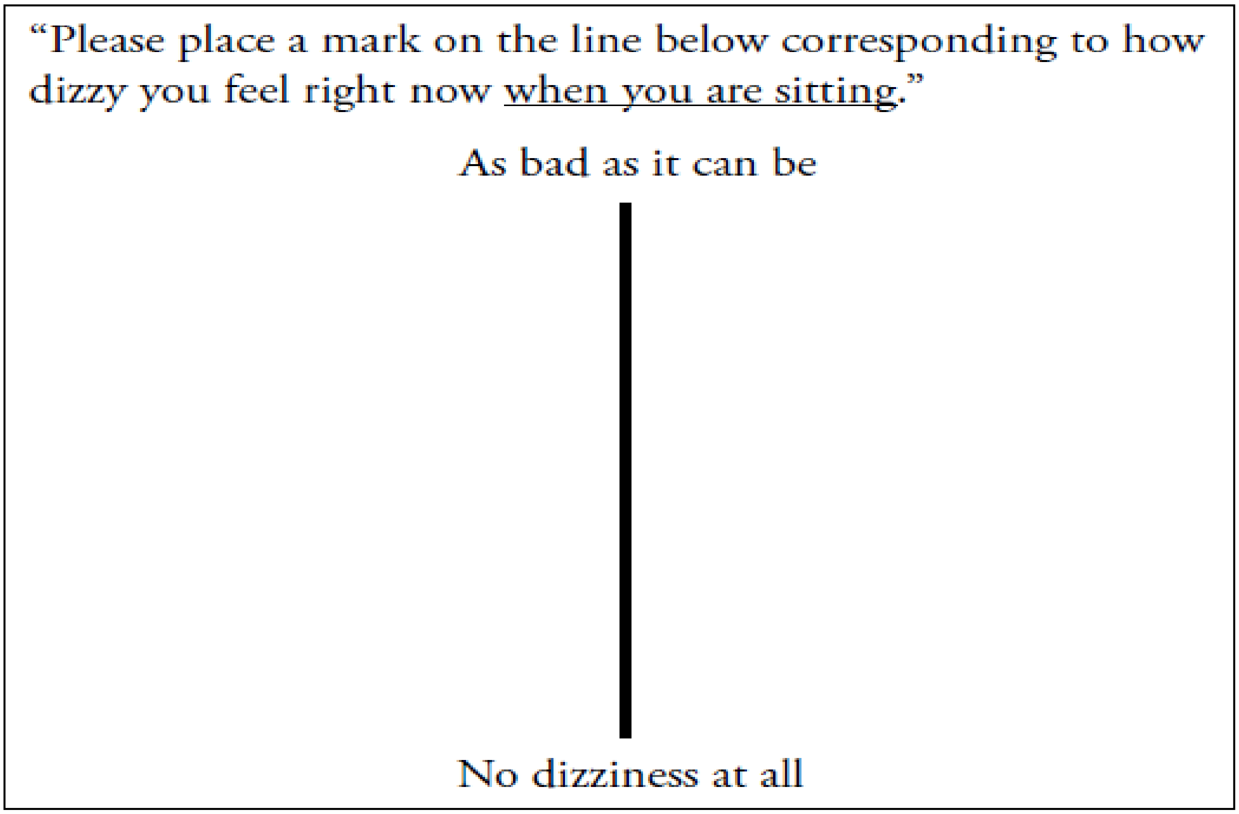


Figure 3-1: Visual Analog Scale of dizziness

3.7.2 Experimental visits

Subjects with vestibular disorders were asked to come for only one experimental visit to perform 2 sets of 16 static standing exercises, whereas, healthy subjects performed the experiment (2 sets of 24 static standing exercises) over two separate visits one week apart. However, patients were offered to perform part of the experiment during their first visit after the screening process section if they had time and were not tired, and perform the remaining of the exercises on a different visit. All patients were able to complete all exercises during their first visit. During the experiment, participants stood without shoes in order to avoid the confounding effect of wearing different shoes. During conditions of the foam surface, subjects stood on a foam pad (AIREX Balance Pad S34-55) that had a height of 6 cm, length of 51 cm, width of 40 cm (density 55 kg/m^3, compression resistance 20 kPa at 25% compression) and the room's temperature was a median value of 72 Fahrenheit degrees with an interquartile range of 3 degrees during all visits to avoid differences in the foam properties (see Appendix C). During the various base of support stances, subjects were asked to distribute their body weight equally on each foot, and to stand during the feet apart condition with their heel centers 0.17 m apart, with an angle of 14 degrees between the long axes of the feet (McIlroy & Maki, 1997). For the semi-tandem stance position, subjects stood with the front foot touching the medial side of the other foot by a half of a foot length (Lee et al., 2012; Nejc, Jernej, Loefler, & Kern, 2010), with dominant foot in the back. The dominant foot was determined by asking the subjects about the foot that they would use to kick a ball (Alonso, Brech, Bourquin, & Greve, 2011; Gabbard & Hart, 1996). During the eyes closed conditions, subjects wore opaque goggles. During yaw and pitch conditions, subjects were instructed to move their head at a frequency of 1 Hz by moving their head to the beat of a metronome (Hall & Herdman, 2006) within a range of 45 degrees in the yaw direction (Jung et al., 2009) and 30 degrees in pitch direction. To ensure that subjects moved their head for 45 degrees in yaw and 30 degrees in pitch directions, they practiced the head movement in these directions with a laser light attached to the head before they started the experiment. However, the laser light was not used during the experiment. Exercises were performed in a random order that was software-generated. Subjects were instructed to stand as stable as possible with arms at their side (Gill-Body et al., 1994; Gill et al., 2001) during all trials for 35 seconds (Allum et al., 2011; Le Clair & Riach, 1996; Muehlbauer et al., 2012; Rine et al., 2013). Data collection was stopped if a subject lost their balance according to the following failure criteria: stepped out of position, changed their feet or arms from the starting position, and/or touched something for support. Subjects were asked to repeat failed trials once in each set if they lost their balance before completing a 25 seconds trial. Subjects were guarded by a physical therapist during all exercises to prevent falling and wore a safety harness which was attached to an anchor point in the ceiling that do not let subject reach the ground in case of a fall incidence. There was a seated rest break for 1 minute after every 3 exercises to avoid fatigue.

In addition, subjects rated their perceived difficulty of each exercise they performed using two different scales. The first scale was a modified rating of perceived difficulty scale based on ratings of perceived exertion scales for aerobic and resistance exercises (Scale A) (Robertson et al., 2004; Robertson et al., 2003) that ranges from 0 to 10, where 0 indicates that the exercise is extremely easy and 10 indicates that the exercise is extremely hard (Figure 3-2). The second scale was developed for this study and was anchored with colors and statements (Scale B) (Espy, Reinthal, Kuchta, Casey, & Wiland, 2015) (Figure 3-3). Scale B had 5 levels ranging from A to E, where A was anchored with the following statement; “I feel completely steady” and E labeled as “I lost my balance”. In the statistical analysis, letters from scale B were transformed to numbers as follows; A = 1, B = 2, C = 3, D = 4, and E = 5.

Before starting the experiment, both scales were explained to subjects. They were told that they needed to choose, after each exercise, a number from the 1st scale and a letter from the 2nd scale that indicated the difficulty of maintaining their balance during that exercise. During the experiment, the scales were placed on the side wall so that subjects could look at them after each exercise.

Please choose from 0 to 10 corresponding to your perceived difficulty of each exercise:

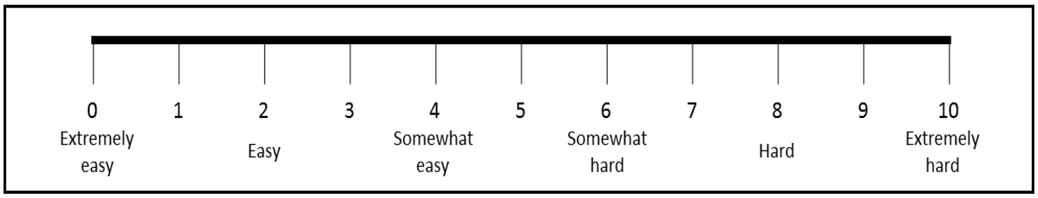


Figure 3-2: Scale A; Rating of perceived difficulty scale, based on OMNI rating of perceived exertion scale (Robertson et al., 2004; Robertson et al., 2003)

Please choose from A to E corresponding to your perceived difficulty of each exercise:	
I feel completely steady	**A**
I feel a little unsteady or off-balance	**B**
I feel somewhat unsteady or like I may lose my balance	**C**
I feel very unsteady or like I definitely will lose my balance	**D**
I lost my balance	**E**

Figure 3-3: Scale B; Rating of perceived difficulty scale, adapted from a poster from Cleveland State University (Espy et al., 2015)

3.8 OUTCOME MEASURES

3.8.1 Demographic data

Demographic data including age, gender, medical diagnosis, weight, and height was summarized by descriptive statistics. Additionally, the average scores of the Functional Gait Assessment, Activities-specific Balance Confidence Scale (ABC) questionnaire, gait speed, Dizziness Handicap Inventory (DHI), and self-report of dizziness on visual analog scale for all groups were recorded.

3.8.2 Postural sway measures

Sway measures were recorded during all trials for 35 seconds each and the first five seconds of data collection were removed in order to avoid the effect of the subject's initial establishment of balance (O'Sullivan, Blake, Cunningham, Boyle, & Finucane, 2009; Rine et al., 2013). Summary measures of trunk sway were calculated from the 30 seconds time series. The data was low-pass filtered using a second order Butterworth filter with a cut-off frequency of 3 Hz (Dozza et al., 2005; Dozza, Horak, et al., 2007). During the analysis, each trial was plotted individually and inspected visually using MATLAB software to make sure that there were no extraneous movements.

Based on a review of the different postural measurements that were used in biofeedback technology studies for quantifying postural sway, I decided to include the following measurements in this study:

The Root Mean Square (RMS) of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions were calculated and used in the analysis to test the hypotheses. The RMS was calculated as follows:

$$\text{RMS} = \sqrt[2]{\frac{\sum_{i=0}^{n}(a_i^2)}{n}},$$

where n is an individual data sample, and N is the total number of samples. The mean value was subtracted before calculating the RMS. Even though the COP data from the pilot study was not normally distributed, I included the RMS to have a measure that is compatible with other studies as it is commonly reported (Chiari et al., 2005; Dozza et al., 2005; Dozza, Horak, et al., 2007; Sienko et al., 2008; Wall, Weinberg, Schmidt, & Krebs, 2001).

Additionally, the 90% range of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions as well as the interquartile range (75^{th} percentile – 25^{th} percentile) of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions were calculated. The 90% range of angular displacement is the difference between the 95^{th} percentile value and the 5^{th} percentile value. The interquartile range is the difference between the upper quartile (the 75^{th} percentile value) and the lower quartile (the 25^{th} percentile value).

3.9 STATISTICAL ANALYSIS

Aim 1: To examine the test-retest reliability of the subjects' performance of standing balance exercises, within and between two visits occurring one week apart.

Participants' demographic characteristics were compared between groups using a one-way ANOVA test for dependent variables that were continuous and normally distributed and post hoc comparisons were conducted to evaluate pairwise differences among the groups. The Sidak approach was used to control for a Type 1 error. The Kruskal-Wallis test was used with dependent variables that were continuous but not normally distributed and Dunn's procedure (Olive Jean Dunn, 1964) was used for pairwise comparisons with a Bonferroni correction for multiple comparisons.

To explore the test-retest reliability of the healthy subjects' performance during the static stance balance exercises, absolute and relative measures of reliability were computed. For relative reliability, the intra-class correlation coefficient (ICC) was used for variables with continuous characteristics (RMS of the trunk angular displacement, and velocity, linear acceleration, and the converted scores of scale B). Model (3) and form (1) of the ICC was used which indicates that each exercise was assessed by each subject, as the subjects were the only subjects of interest, and reliability was calculated from a single measurement. Furthermore, a weighted Kappa (linear weight) was used with the ordinal data (rating values of perceived difficulty) to assess the test-retest agreement. Test-retest reliability was assessed within the 2 trials of each visit, between the first sessions of both visits, between the second sessions of both visits, and between the averages of both sessions from each visit. Intra-class correlation coefficient (ICC) reliability scores range from 0 to 1.0 where excellent reliability ranges from 0.75 to 1.0, fair to good reliability ranges from 0.4 to 0.74 and poor reliability ranges from 0 to 0.4 (Fleiss, 1999). Weighted Kappa scores range from 0 to 1 where excellent agreement ranges from 0.81 to 1, substantial agreement ranges from 0.61 to 0.80, moderate agreement ranges from 0.41 to 0.60, fair agreement ranges 0.21 to 0.40, and poor agreement ranges from 0.01 to 0.20

(Viera & Garrett, 2005). To assess the absolute reliability, the standard error of measurement (SEM), Bland and Altman plots, and minimal detectable change (MDC) were assessed.

The Standard Error of Measurement (SEM) was calculated as follow: SEM = $SD * \sqrt{1-r}$, where r equals to the reliability coefficient, The Minimal Detectable Change (MDC) was calculated as follow: MDC = $1.96 * \sqrt{2} * SEM$.

The scores of Scale B were converted from ordinal to continuous scores using Item Response Theory (IRT). The continuous converted scores are the estimated probability of reporting an exercise as a difficult exercise, which is a function of how difficult the exercise is and how well that exercise discriminates someone with a high rating level of the difficulty performing a balance task from someone with low level of difficulty.

Aim 2: To validate two scales of rating of perceived difficulty of balance exercises by comparing the scales with quantitative sway measures.

Hypothesis 1: On a within subject basis, rating of perceived difficulty will increase as trunk tilt and center of pressure displacement increase.

To assess the concurrent validity of the rating of perceived difficulty scales, the relationship between rating of perceived difficulty and postural variables were assessed using the multiple regression method (Bland & Altman, 1995). For either relationship, the rating of perceived difficulty was the outcome variable and the subjects and postural measures were the predictor variables. From the regression analysis of variance table, the amount of variation in rating of perceived difficulty due to variation in postural measure magnitude, while controlling for the intersubject variability, was computed by the following formula: Correlation = sqrt ($SS_{\text{postural measure}}$ / $SS_{\text{postural measure}}$ + SS_{residual}), where SS is the sum of squares. The direction of the correlation is given by the sign of the slope of the regression coefficient between the rating of perceived difficulty and postural measure. Correlation coefficients were calculated for rating of perceived difficulty and all of the postural variables listed previously, in order to examine if the rating of perceived difficulty is more highly related to some postural variables than others.

Aim 3: To examine the perceptual difficulty and postural measures of static standing balance exercises in healthy adults from 18 to 85 y/o

Hypothesis 1:

During the performance of balance exercises, trunk tilt sway measures and rating of perceived difficulty will increase from the youngest to the oldest age group.

Hypothesis 2:

Trunk tilt sway measures and rating of perceived difficulty will increase as static stance balance exercises change from: level surface to foam surface, eyes open to eyes closed, head still to yaw or pitch movement, and feet apart to semi-tandem stance.

Hypothesis 3:

The increase in magnitude of trunk tilt sway measures will be greater as age increases and as static stance balance exercises change from: level surface to foam surface, eyes open to eyes closed, head still to yaw or pitch movement, and feet apart to semi-tandem stance.

Participants’ demographic characteristics were compared between groups using one-way ANOVA test for dependent variables that were continuous and normally distributed and post hoc comparisons were conducted to evaluate pairwise differences among the groups and the Sidak approach was used to control for Type 1 error. The Kruskal-Wallis test was used with dependent variables that were continuous but not normally distributed and Dunn's procedure (Olive Jean Dunn, 1964) was used for pairwise comparisons with a Bonferroni correction for multiple comparisons.

Postural Sway:

A Linear Mixed Model (LMM) was used to test the three hypotheses of the study. A linear mixed model was used to explore the main effects of five independent variables; age group and four exercise conditions (types of stance, visual input, surface, and head movements) as well as to explore two-way interaction effects between age groups and surface types, visual inputs, stance types, and head movements on quantitative postural measures (RMS of trunk angular displacement and velocity in the pitch and roll directions, and trunk linear acceleration in the AP and ML acceleration). LMM contains fixed effects and random effects. In this study, fixed effects are age groups, surface types, visual inputs, stance conditions, and head movements, whereas the random effect is subjects. Due to the presence of missing data in this study, the decision was made to use a LMM as it allows us to evaluate the effects with the presence of having missing data. Additionally, LMM allows inclusion of a random effect, subjects, and assumes that each subject has his/her own intercept value.

The autoregressive order 1 (AR1) covariance structure was used, which assumes homogeneous variance and unequal covariance between observations on the same subject. Several different covariance structures were evaluated and AR1 had the best model fits and best reflected the unadjusted means.

The average value of all 4 trials of the dependent variables (2 trials per visit and 2 visits) were used because it was determined that there was no difference between trials or visits. A Sidak correction for multiple comparisons was used for post-hoc analysis of significant main effects related to age and head movement. Normality was tested using the Shapiro–Wilk test. The significance level was $\alpha = 0.05$.

Rating of Perceived Difficulty:

For rating of perceived difficulty data, which was ordinal, the Kruskal-Wallis test was used for comparison of more than two independent samples (age groups) and Dunn's procedure was used for pairwise comparisons with a Bonferroni correction for multiple comparisons. The Friedman test was used for comparison of more than two dependent samples (head movement conditions) followed by Wilcoxon signed-rank tests for pairwise comparisons with a Bonferroni correction for multiple comparisons. Wilcoxon signed-rank test was used for comparison of two dependent samples (surface conditions, visual inputs, stance conditions). The mean value of all 4 trials (2 trials per visit and 2 visits) of the rating of perceived difficulty from Scales A & B was used.

Static Standing Balance Exercises Sequence:

A hierarchical cluster analysis (HCA) was used to categorize the exercises into five clusters (very easy, easy, moderate, hard, and very hard) to help physical therapists to establish a scientific basis for exercise progression. The HCA was conducted using the pitch and roll tilt velocity measures because they were determined to have the greatest reliability, and both ratings of perceived difficulty scales.

Aim 4: To examine the effect of vestibular disorders on the magnitude of trunk tilt and center of pressure displacement during performance of different types of static standing balance exercises.

Hypothesis 1:

Individuals with vestibular disorders will have greater trunk tilt, center of pressure displacement, and rating of perceived difficulty during the performance of standing balance exercises compared with healthy age-matched controls.

Hypothesis 2:

Individuals with vestibular disorders will have an increase in postural sway and rating of perceived difficulty as static standing balance exercises change from level surface to foam surface, eyes open to eyes closed, head still to yaw movement, and feet apart to semi-tandem stance.

Hypothesis 3:

The increase in magnitude of trunk tilt, center of pressure displacement, and rating of perceived difficulty as static stance balance exercises change from: level surface to foam surface, eyes open to eyes closed, head still to yaw movement, and feet apart to semi-tandem stance, will be greater in individuals with vestibular disorders compared with healthy age-matched controls.

Participants' demographic characteristics were compared between groups using independent samples t-test for dependent variables that were continuous and normally distributed. The Mann-Whitney U test was used to compare differences between the two independent groups when dependent variables were continuous but not normally distributed.

Postural Sway:

A Linear Mixed Model (LMM) was used to test the three hypotheses of the study. The LMM contains fixed effects and random effects. In this study, fixed effects are groups, surface types, visual inputs, stance conditions, and head movements, whit a random effect for subjects. Due to the presence of missing data in this study, the decision was made to use LMM as it allows us to evaluate the effects with the presence of having missing data. Additionally, the LMM allows inclusion of a random effect, subjects, and assumes that each subject has his/her own intercept value. The LMM was used to explore main effects of the fixed effects and two-way interaction effects between groups and stances, visual inputs, surfaces, and head movements on quantitative postural measures (RMS of trunk tilt in pitch displacement, roll displacement, pitch velocity, roll velocity, AP acceleration, and ML acceleration).

The autoregressive order 1 (AR1) covariance structure was used, which assumes homogeneous variance and unequal covariance between observations on the same subject. Several different covariance structures were evaluated and AR1 had the best model fits and best reflected the unadjusted means.

The average value of the 2 trials of the dependent variables was used because it was determined that there was no difference between trails. Due to the high incompletion rate of exercise 23 especially for people with vestibular data, it was eliminated from the linear mixed model analysis. Normality was tested using the Shapiro–Wilk test. The significance level was $\alpha = 0.05$.

Ratings of Perceived Difficulty:

For rating of perceived difficulty data, which was ordinal, the Mann-Whitney U test was used to compare differences in ratings of perceived difficulty between the two groups, and the Wilcoxon signed-rank test was used for comparison of two dependent samples (surface conditions, visual inputs, stance conditions, and head movements). The mean value of the 2 trials of the ratings of perceived difficulty from Scales A & B was used.

4.0 VALIDITY AND RELIBILITY OF POSTURAL SWAY MEASURES AND RATINGS OF PERCEIVED DIFFICULTY OF STATIC STANDING BALANCE EXERCISES

4.1 INTRODUCTION

Standing balance is the ability to keep the center of mass of the body over its base of support with minimal postural sway (Horak, 1987; Shumway-Cook, Anson, & Haller, 1988; D. A. Winter, 1995). Maintaining balance requires integration of afferent sensory inputs from the visual, vestibular, and proprioception systems. The brain processes the afferent inputs and produces the appropriate motor response to keep the body balanced. Age-related decline (Baloh et al., 1994; Baloh et al., 1998; Gill et al., 2001; Rogind et al., 2003; Sheldon, 1963; Sullivan et al., 2009) or a deficit in the function of peripheral balance sensory systems (Kerber et al., 2006; Lichtenstein et al., 1988; Lord et al., 1991a, 1991b), central balance-related structures and related cognitive function (Baloh et al., 2003; Sullivan et al., 2009; Tell et al., 1998), and/or lower limb muscles (Aniansson et al., 1986; Larsson et al., 1979) can result in postural instability and therefore increase the risk of falling and injury (Fernie et al., 1982; Hilliard et al., 2008; Maki et al., 1994; Nanhoe-Mahabier et al., 2012; Stalenhoef et al., 2002).

Balance training has been found to be useful for all age groups in improving mobility and functionality (Franco, Pereira, & Ferreira, 2014; Gillespie et al., 2012; Horak et al., 1992; Howe, Rochester, Neil, Skelton, & Ballinger, 2011). Customized balance exercises and vestibular rehabilitation therapy (VRT) are considered to be effective options to improve balance by facilitating the central nervous system's ability to compensate for balance deficits (Gillespie et al., 2012; Hillier & McDonnell, 2011; Horak et al., 1992; Howe et al., 2011; Shepard & Telian, 1995). These treatments have elicited beneficial results in improving balance in older adults and people with vestibular disorders, eliminating the symptoms of vestibular disorders, and reducing falls (Gillespie et al., 2012; Hillier & McDonnell, 2011; Horak et al., 1992; Howe et al., 2011). Similarly, a number of studies that have investigated ways to prevent falls have found that balance training is an important key in reducing falls in the elderly (Barnett, Smith, Lord, Williams, & Baumand, 2003; Franco et al., 2014; Gillespie et al., 2012; Nitz & Choy, 2004).

Balance and vestibular rehabilitation therapy is comprised of different categories of exercises such as static standing, weight shifting, anticipatory postural adjustments, gait, and eye-head coordination (Alsalaheen et al., 2013; Klatt et al., 2015). During balance and vestibular rehabilitation, physical therapists progress the challenge of balance exercises by reducing sensory input (e. g. standing on foam or closing eyes), changing the base of support (e. g. standing in semi-tandem stance), and perturbing the balance system (e. g. moving the head in yaw or pitch directions). The progression of exercises' challenge usually is done based on experience rather than rubrics based on evidence (Klatt et al., 2015).

The evidence in determining the appropriate progression of balance exercises is very limited according to the American College of Sports Medicine (ACSM) (Pescatello & American College of Sports Medicine., 2014). The American College of Sports Medicine recommended a progression pattern by altering different conditions such as reducing the base of support by changing from feet apart to feet together, to semi-tandem, to tandem, to standing on one foot; by changing the visual input from eyes open to eyes closed; or by changing the surface compliance from firm surface to foam surface (Pescatello & American College of Sports Medicine., 2014). However, it is not certain how modifying these factors is equated to balance exercise intensity.

For aerobic and resistance exercises, there are very well defined rules for how to determine the initial prescription for exercise intensity as well as how to increase the intensity level based on the fitness level of the trainee. According to the American College of Sports and Medicine (ACSM), the intensity of aerobic exercise is the percentage of the heart rate reserve, where 40-60% of the heart rate reserve is considered a moderate intensity which may be progressed to a vigorous intensity (60-85%) during endurance training and general aerobic exercises. The prescribed intensity may vary depending on the fitness level and goals of the trainee, and whether the trainee has any chronic diseases (Pescatello & American College of Sports Medicine., 2014). Similarly, the intensity of resistance training is defined as a percentage of one repetition maximum (1RM), which is the maximum weight that can be lifted once through the full range of motion. The ACSM recommends different intensity ranges depending on the type of exercise, whether it is muscular strength, endurance, or enlargement, and also the intensity depends on the level of the trainee (beginner: a non-trained person and has no experience exercising; intermediate: a person who has experience practicing for 6 months; or advanced: a person who exercised and has experience for years (American College of Sports, 2009)). For instance, to increase muscular strength, it is recommended that the intensity is between 60-70% of 1RM for novice and intermediate and between 80-100% for advanced trainees. For muscular endurance, the ACSM recommends that the intensity of the resistance exercises is lower than 70% of 1RM, whereas, it is suggested for novice and intermediate trainees to lift weights between 70-85% of 1RM and 70-100% for advanced trainees in order to increase muscle mass (Pescatello & American College of Sports Medicine., 2014).

Furthermore, the rating of perceived exertion for aerobic and resistance exercises was developed to assist in determining how trainees perceive the intensity of activity in cases where the heart rate reserve or the maximum weight that can be lifted are not possible to be measured due to medical conditions, using a medication that affects the heart rate in response to physical effort, or lack of medical equipment to measure the event of interest (Robertson et al., 2004; Robertson et al., 2003; Utter et al., 2004). During training programs, ratings of perceived exertion scales help to monitor the intensity of the activity and provide healthcare providers with feedback of how hard their clients' feel like they are exercising as well as if their clients are ready to progress to the next level of intensity.

During the performance of balance exercises, measuring or visually observing the amount of sway is a common way of assessing the difficulty of exercises. However, many clinics don't have the capability to measure sway or interpret the sway results. Therefore, in this study, we aimed to validate ratings of perceived difficulty scales for static standing balance exercises to help to determine the intensity of balance exercises and progress them in cases when measuring sway is not an option. This study is part of a larger study that aimed to guide the progression of static standing balance exercises using elicited quantitative measures of balance and an individual's perception of difficulty of the different balance exercises in static standing.

The purpose of this study was to examine the test-retest reliability of subjects' performance during standing balance exercises, within and between two visits occurring one week apart. The second aim of the study was to validate two scales of rating of perceived difficulty of balance exercises by comparing the scales with quantitative sway measures.

4.2 METHODS

4.2.1 Participants

Sixty-two healthy subjects who were independently participating in daily activities and were between the ages of 18 and 85 years old (31 females and 31 males, mean age 28 ± 8 years) participated in this study. Study participants were distributed into four groups: young (18-44 years old), middle-aged (45-59 years old), old (60-74 years old), and very old (75-85 years old). Age divisions were developed based on age-related changes in the postural sway found in several studies (Abrahamova & Hlavacka, 2008; Baloh et al., 1998; Era et al., 2006; Gill et al., 2001; Liaw et al., 2009; Rosenhall & Rubin, 1975; Sheldon, 1963).

Subjects were excluded if they were unable to stand for 3 minutes without rest; had distal sensory loss (unable to complete the Romberg test for 30 seconds and unable to feel a pressure of a 4.31 g monofilament applied on the dorsum of the foot and the medial side of the foot below the medial malleolus with eyes closed); had visual acuity worse than 20/40, had a diagnosis of benign paroxysmal positional vertigo (BPPV) (positive Dix–Hallpike test or positive Roll test); had a history of neurological or orthopedic disorders; used an assistive device for ambulation; were pregnant; had excessive weight (BMI > 35); had cognitive impairment (≤ 25 points on the Montreal Cognitive Assessment); had a history of falling 2 times or more within the last 12 months doing activities of daily living; or had a peripheral vestibular disorder (positive head thrust test).

This study was approved by the Institutional Review Board in University of Pittsburgh. All subjects signed the written research consent form prior to participating in the study.

4.2.2 Instrumentation

During the performance of the exercises in static standing, subjects stood on a force platform (NeuroTest, NeuroCom, Inc., Clackamas, OR) that measured ground reaction forces at a sampling rate of 100 Hz. An inertial measurement unit (IMU, Xsense Technologies B.V., Enschede, The Netherlands) was mounted on each subject's lower back at the level of iliac crest (L4) to measure trunk angular displacement and velocity from vertical and linear acceleration in AP and ML directions at a sampling rate of 100 Hz. The IMU uses a combination of accelerometers, gyroscopes, and a magnetometer.

4.2.3 Experimental procedure

The study is a cross-sectional study to determine test-retest reliability of the subjects' performance of static standing balance exercises, within and between two visits occurring one week apart and to establish concurrent validity of two scales of rating of perceived difficulty of balance exercises by comparing the scales with quantitative postural sway measures.

All potential research participants had a screening visit. The eligible subjects were asked to come back for two testing visits one week apart.

4.2.3.1 Screening visit

Consented subjects underwent screening tests to rule out conditions known to adversely affect balance. Screening tests included; Romberg stance (Horak, 1987), lower extremities pressure threshold using monofilaments (Holewski et al., 1988), visual acuity test (Brien Holden, 2008; Muhammad et al., 2015; World-Health-Organization, 2003), the Montreal Cognitive Assessment

- Version 3 (Nasreddine et al., 2005), the Dix–Hallpike Test (Dix & Hallpike, 1952), the supine roll test (Lempert & Tiel-Wilck, 1996), and the head impulse test (Halmagyi & Curthoys, 1988).

Eligible subjects who met the study criteria completed the Activities-specific Balance Confidence Scale (ABC) questionnaire (Powell & Myers, 1995), the Functional Gait Assessment (FGA) (Wrisley et al., 2004), and their gait speed (Steffen et al., 2002) was recorded prior to the experiment in order to better describe the participants. A more detailed description of the screening tests is in Chapter 3.

4.2.3.2 Experimental visits

Participants were tested during two experimental visits, one week apart. During each experimental visit, participants performed two sets of 24 randomized static standing balance exercises, which were a full-factorial design of the following different conditions: vision (eyes open and eyes closed); surface (firm and foam); base of support (feet apart and semi-tandem); head movements (head still, yaw, and pitch) as shown in Table 4-1.

Table 4-1: Balance and vestibular exercises

Exercise number	Surface conditions	Visual input	Base of support	Head movement
1	Firm	Eyes open	Feet apart	Head still
2	Firm	Eyes open	Feet apart	Yaw
3	Firm	Eyes open	Feet apart	Pitch
4	Firm	Eyes open	Semi-tandem	Head still
5	Firm	Eyes open	Semi-tandem	Yaw
6	Firm	Eyes open	Semi-tandem	Pitch
7	Firm	Eyes closed	Feet apart	Head still
8	Firm	Eyes closed	Feet apart	Yaw
9	Firm	Eyes closed	Feet apart	Pitch
10	Firm	Eyes closed	Semi-tandem	Head still
11	Firm	Eyes closed	Semi-tandem	Yaw
12	Firm	Eyes closed	Semi-tandem	Pitch
13	Foam	Eyes open	Feet apart	Head still
14	Foam	Eyes open	Feet apart	Yaw
15	Foam	Eyes open	Feet apart	Pitch
16	Foam	Eyes open	Semi-tandem	Head still
17	Foam	Eyes open	Semi-tandem	Yaw
18	Foam	Eyes open	Semi-tandem	Pitch
19	Foam	Eyes closed	Feet apart	Head still
20	Foam	Eyes closed	Feet apart	Yaw
21	Foam	Eyes closed	Feet apart	Pitch
22	Foam	Eyes closed	Semi-tandem	Head still
23	Foam	Eyes closed	Semi-tandem	Yaw
24	Foam	Eyes closed	Semi-tandem	Pitch

Participants stood without shoes in order to avoid the confounding effect of wearing different shoes. During conditions of the foam surface, subjects stood on a foam pad (AIREX Balance Pad S34-55) that had a height of 6 cm, length of 51 cm, width of 40 cm (density 55 kg/m^3, compression resistance 20 kPa at 25% compression) and the room's temperature was a median value of 72 Fahrenheit degrees with an interquartile range of 3 degrees during all visits to avoid differences in the foam properties (see Appendix C). During the various base of support stances, subjects were asked to distribute their body weight equally on each foot, and to stand during the feet apart condition with their heel centers 0.17 m apart, with an angle of 14 degrees between the long axes of the feet (McIlroy & Maki, 1997). For the semi-tandem stance position, subjects stood with the front foot touching the medial side of the other foot by a half of a foot length (Lee et al., 2012; Nejc et al., 2010), with the dominant foot in the back. The dominant foot was determined by asking the subjects about the foot that they would use to kick a ball (Gabbard & Hart, 1996). During the eyes closed conditions, subjects wore opaque goggles. During yaw and pitch conditions, subjects were instructed to move their head at a frequency of 1 Hz by moving their head to the beat of a metronome (Hall & Herdman, 2006) within a range of 45 degrees in the yaw direction (Jung et al., 2009) and 30 degrees in pitch direction. To ensure that subjects moved their head for 45 degrees in yaw and 30 degrees in pitch directions, they practiced the head movement in these directions with a laser light attached to the head before they started the experiment. However, the laser light was not used during the experiment. Exercises were performed in a random order that was software-generated. Subjects were instructed to stand as stable as possible with arms at their side (Gill-Body et al., 1994; Gill et al., 2001) during all trials for 35 seconds (Allum et al., 2011; Le Clair & Riach, 1996; Muehlbauer et al., 2012; Rine et al., 2013). Data collection was stopped if a subject lost their balance according to the following failure criteria: stepped out of position, changing their feet or arms from the starting position, and/or touching something for support. Subjects were asked to repeat failed trials once in each set if they lost their balance before completing a 25 seconds trial. Subjects were guarded by a physical therapist during all exercises to prevent falling and wore a safety harness which was attached to an anchor point in the ceiling that do not let subject reach the ground in case of a fall incidence but would allow them to move freely. There was a seated rest break for 1 minute after every 3 exercises to avoid fatigue.

In addition, subjects rated their perceived difficulty of each exercise they performed using two different scales. The first scale was a modified rating of perceived difficulty scale based on ratings of perceived exertion scales for aerobic and resistance exercises (Scale A) (Robertson et al., 2004; Robertson et al., 2003) that ranges from 0 to 10, where 0 indicates that the exercise is extremely easy and 10 indicates that the exercise is extremely hard (Figure 4-1). The second scale was developed for this study and was anchored with colors and statements (Scale B) (Espy et al., 2015) (Figure 4-2). Scale B had 5 levels ranging from A to E, where A was anchored with the following statement; "I feel completely steady" and E labeled as "I lost my balance". In the statistical analysis, letters from scale B were transformed to numbers as follows; A = 1, B = 2, C = 3, D = 4, and E = 5.

Before starting the experiment, both scales were explained to subjects. They were told that they needed to choose, after each exercise, a number from the 1st scale and a letter from the 2nd scale that indicated the difficulty of maintaining their balance during that exercise. During the experiment, the scales were placed on the side wall so that subjects could view at them after each exercise.

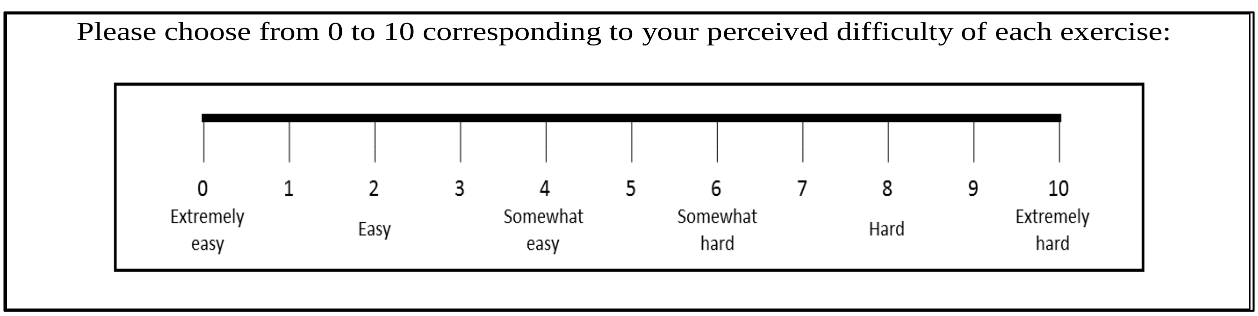


Figure 4-1: Scale A; Rating of perceived difficulty scale, based on OMNI rating of perceived exertion scale (Robertson et al., 2004; Robertson et al., 2003)

Please choose from A to E corresponding to your perceived difficulty of each exercise:	
I feel completely steady	**A**
I feel a little unsteady or off-balance	**B**
I feel somewhat unsteady or like I may lose my balance	**C**
I feel very unsteady or like I definitely will lose my balance	**D**
I lost my balance	**E**

Figure 4-2: Scale B; Rating of perceived difficulty scale, adapted from a poster from Cleveland State University (Espy et al., 2015)

4.2.4 Outcome measures

Demographic data:

Demographic data including age, gender, weight, and height was summarized by descriptive statistics. Additionally, the average scores of the Functional Gait Assessment, Activities-specific Balance Confidence Scale (ABC) questionnaire, and gait speed for all groups were recorded.

Sway measures:

Sway measures were recorded during all trials for 35 seconds and the first five seconds of data collection were removed in order to avoid the effect of the subject's initial establishment of balance (O'Sullivan et al., 2009; Rine et al., 2013). Summary measures of trunk sway were calculated from the 30 seconds time series. The data was low-pass filtered using a second order Butterworth filter with a cut-off frequency of 3 Hz (Dozza et al., 2005; Dozza, Horak, et al., 2007). During the analysis, each trial was plotted individually and inspected visually using MATLAB software to make sure that there were no extraneous movements.

The Root Mean Square (RMS) of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions were calculated and used in the analysis to test the hypotheses. The RMS was calculated as follows:

$$\text{RMS} = \sqrt[2]{\frac{\sum_{i=0}^{n}(a_i^2)}{n}}$$

where a is instantaneous sway value with mean value subtracted, and n is an individual data sample, and N is the total number of samples. The mean value was subtracted before calculating the RMS.

Additionally, the 90% range of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions as well as the interquartile range (75th percentile – 25th percentile) of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions were calculated. The 90% range of angular displacement is the difference between the 95th percentile value and the 5th percentile value. The interquartile range is the difference between the upper quartile (the 75th percentile value) and the lower quartile (the 25th percentile value). The previous two measures were collected to set ranges of normal limits of sway for different age groups. Additionally, these values could be used for augmented sensory feedback devices to set the threshold when a feedback can be provided.

4.2.5 Statistical Analyses

Participants' demographic characteristics were compared between groups using a one-way ANOVA test for dependent variables that were continuous and normally distributed and post hoc comparisons were conducted to evaluate pairwise differences among the groups. The Sidak approach was used to control for a Type 1 error (Sidak, 1967). The Kruskal-Wallis test was used with dependent variables that were continuous but not normally distributed and Dunn's procedure (Olive Jean Dunn, 1964) was used for pairwise comparisons with a Bonferroni correction for multiple comparisons.

To explore the test-retest reliability of the healthy subjects' performance during the static stance balance exercises, absolute and relative measures of reliability were computed. For relative reliability, the intra-class correlation coefficient (ICC) was used for variables with continuous characteristics (RMS of the trunk angular displacement, and velocity, linear acceleration, and the converted scores of scale B). Model (3) and form (1) of the ICC was used which indicates that each exercise was assessed by each subject, as the subjects were the only subjects of interest, and reliability was calculated from a single measurement. Furthermore, a weighted Kappa (linear weight) was used with the ordinal data (rating values of perceived difficulty) to assess the test-retest agreement. Test-retest reliability was assessed within the two trials of each visit, between the first sessions of both visits, between the second sessions of both visits, and between the averages of both sessions from each visit. Intra-class correlation coefficient (ICC) reliability scores range from 0 to 1.0 where excellent reliability ranges from 0.75 to 1.0, fair to good reliability ranges from 0.4 to 0.74 and poor reliability ranges from 0 to 0.4 (Fleiss, 1999). Weighted Kappa scores range from 0 to 1 where excellent agreement ranges from 0.81 to 1, substantial agreement ranges from 0.61 to 0.80, moderate agreement ranges from

0.41 to 0.60, fair agreement ranges 0.21 to 0.40, and poor agreement ranges from 0.01 to 0.20 (Viera & Garrett, 2005). To assess the absolute reliability, the standard error of measurement (SEM), Bland and Altman plots, and minimal detectable change (MDC) were assessed.

The Standard Error of Measurement (SEM) was calculated as follow: SEM = $SD * \sqrt{1-r}$, where r equals to the reliability coefficient. The Minimal Detectable Change (MDC) was calculated as follow: MDC = $1.96 * \sqrt{2} * \text{SEM}$.

The scores of Scale B were converted from ordinal to continuous scores using Item Response Theory (IRT) (Hays, Morales, & Reise, 2000). The continuous converted scores are the estimated probability of reporting an exercise as a difficult exercise, which is a function of how difficult the exercise is and how well that exercise discriminates someone with a high rating level of the difficulty performing a balance task from someone with low level of difficulty.

To assess the concurrent validity of the rating of perceived difficulty scales, the relationship between rating of perceived difficulty and postural variables were assessed using the multiple regression method (Bland & Altman, 1995). For either relationship, the rating of perceived difficulty was the outcome variable and the subjects and postural measures were the predictor variables. From the regression analysis of variance table, the amount of variation in rating of perceived difficulty due to variation in postural measure magnitude, while controlling for the intersubject variability, was computed by the following formula: Correlation = sqrt ($SS_{\text{postural measure}}$ / $SS_{\text{postural measure}}$ + SS_{residual}), where SS is the sum of squares. The direction of the correlation is given by the sign of the slope of the regression coefficient between the rating of perceived difficulty and postural measure. Correlation coefficients were calculated for rating of perceived difficulty and all of the postural variables listed previously, in order to examine if the rating of perceived difficulty is more highly related to some postural variables than others.

4.3 RESULTS

4.3.1 Descriptive statistics

Of 72 people who underwent onsite screening, 62 participants completed the study and were assigned into four groups as shown in Table 4-2. The 10 subjects who did not complete the study had a mean age of 64 ± 14 years. Eight subjects were excluded because they did not pass the inclusion criteria (4 did not pass the cognitive test; 3 did not pass the monofilament test; 1 did not pass the roll test), 1 subject was excluded due to a behavioral issue, and 1 subject did not come back for follow up visits. The remaining 62 participants had a mean age of 55 ± 20 years. The mean values of gait speed for all age groups were within the normal range (Abellan et al., 2009; Hornyak, VanSwearingen, & Brach, 2012; Lusardi, Marjorie, & Schulman, 2003), and within high levels of physical functioning based on their scores of the Functional Gait Assessment (FGA) (Walker et al., 2007; Wrisley & Kumar, 2010) and Activities-specific Balance Confidence (ABC) Scale (Huang & Wang, 2009; Myers, Fletcher, Myers, & Sherk, 1998; Powell & Myers, 1995).

Table 4-2: Participants' Demographic Characteristics

	All participants (18-85)	Young (18-44)	Middle aged (45-59)	Old (60-74)	Very old (75-85)
	Total (n=62)	Total (n=17)	Total (n=15)	Total (n=15)	Total (n=15)
Age, y, M ± SD	55 ± 20	28 ± 8	53 ± 4	67 ± 4	79 ± 3
Gender, female, n (%)	31 (50)	9 (53)	8 (53)	7 (47)	7 (47)
Body Mass Index, kg/m^2, Median (Range)	26.3 (15.5-35.8)	21.8 (18.1-33.5)	27.5 (18.1-32.1)	29.9 (15.5-34.8)	27.8 (19.9-35.8)
Monofilament, Median (Range)	4.08 (2.83-4.31)	3.84 (2.83-4.08)	4.08 (2.83-4.31)	4.08 (3.61-4.17)	4.17 (3.61-4.31)
Montreal Cognitive Assessment, Median (Range)	29 (26-30)	29 (26-30)	28 (26-30)	29 (26-30)	28 (26-30)
The Activities-specific Balance Confidence (ABC) Scale, Median (Range)	97 (81-100)	99 (89-100)	94 (83-100)	98 (81-100)	91 (88-99)
Gait Speed, m/s, M ± SD	1.30 ± 0.20	1.38 ± 0.20	1.39 ± 0.21	1.26 ± 0.19	1.16 ± 0.12
Functional Gait Assessment, Median (Range)	28 (11)	29 (27-30)	29 (23-30)	28 (19-30)	24 (19-29)

A one-way ANOVA was conducted to test the differences between the four age groups (Young, Middle aged, Old, Very old) on gait speed. There was a significant difference between groups on gait speed [F (3, 58) = 5.26, p = 0.003]. Post hoc comparisons were conducted to evaluate pairwise differences among the four groups and indicated that the mean score of the young group (M = 1.38, SD = 0.2 m/s) and the middle-aged group (M = 1.39, SD = 0.21 m/s) were significantly different from the very old group (M = 1.16, SD = 0.12 m/s).

A Kruskal-Wallis test was conducted to evaluate differences among the four age groups (Young, Middle aged, Old, and Very old) on the Body Mass Index (BMI), the Activities-specific Balance Confidence Scale (ABC), and the Functional Gait Assessment (FGA). There was a significant difference between groups on all of the above variables. Subsequently, pairwise comparisons were performed using Dunn's procedure (Olive Jean Dunn, 1964) with a Bonferroni correction for multiple comparisons. The pairwise comparisons showed significant differences between the young group and the old group, and the very old group on their BMI, the young group and the very old group on the ABC, and between the very old group and all the other groups (young, middle aged, and old) on the FGA.

Reviewing the rate of successfully completed exercises in each age group revealed that most subjects in the young group were able to complete all exercises with the exception of No. 23 (foam surface, eyes closed, semi-tandem stance, and yaw head movement) with an incompletion rate of 14.7%. The majority of the middle-aged group could complete all exercises except No. 23 (foam surface, eyes closed, semi-tandem stance, and yaw head movement), and No. 24 (foam surface, eyes closed, semi-tandem stance, and pitch head movement) with an incompletion rate of 66.7%, and 65% respectively. Subjects in the old group had more difficulty completing the exercises (No. 17 (foam surface, eyes open, semi-tandem stance, and yaw head movement), No. 18 (foam surface, eyes open, semi-tandem stance, and pitch head movement), No. 23, and No. 24) with higher rates (13.3 – 73.3%) of incompletion. The number of exercises that subjects aged 75 through 85 years could not perform increased compared with other groups: (No. 11 (firm surface, eyes closed, semi-tandem stance, and yaw head movement), No. 12 (firm surface, eyes closed, semi-tandem stance, and pitch head movement), No. 17, No. 18, No. 21 (foam surface, eyes closed, feet apart stance, and pitch head movement), No. 22 (foam surface, eyes closed, semi-tandem stance, and head still), No. 23, and No. 24) with incompletion rates ranging between 11.7% - 96.7% (see Table 4-3).

Table 4-3: Incompletion rates of balance and vestibular exercises

Exercise number	Incompletion rate (%)			
	Group 1	Group 2	Group 3	Group 4
1				
2				
3				
4				1.7
5				3.3
6			1.7	
7				
8		1.7		
9				
10				5.0
11		5.0	6.7	31.7
12				20.0
13				1.7
14				
15				6.7
16				1.7
17		6.7	13.3	46.7
18		10.0	21.7	51.7
19				
20			5.0	8.3
21			3.3	11.7
22		3.3	6.7	35.0
23	14.7	66.7	73.3	96.7
24	7.4	65.0	63.3	85.0

4.3.2 Test-retest reliability

An intra-class correlation coefficient (ICC) was used to explore the test-retest reliability of healthy subjects' performance of 24 static stance balance exercises within and between two visits occurring one week apart.

The test-retest reliability was calculated for the RMS of trunk angular displacement, velocity, and linear acceleration in the anteroposterior and mediolateral directions for each exercise separately. The average scores of the ICC coefficients of the RMS of trunk angular velocity were higher than the average scores of the coefficients of RMS of trunk tilt displacement in both pitch and roll and linear acceleration in the AP and ML directions. Additionally, the sway measures in the roll direction were more reliable in more exercises compared to sway measures in the pitch direction. (see Tables 4-4, 4-5, 4-6, 4-7 and 4-8, and Figures 4-3, 4-4, 4-5, 4-5, 4-6, 4-7, 4-8, 4-9, and 4-10).

Table 4-4: The average intraclass correlation coefficients (ICC 3,1) of the RMS of trunk tilt displacement, velocity, and acceleration across the 24 exercises, standard deviation (SD), and the number of exercises with poor reliability

	Within 1st visit (session 1 & 2)		Within 2nd visit (session 1 & 2)		Between visits (Trial 1 Vs. 3)		Between visits (Trial 2 Vs. 4)	
	ICC (SD)	# of exercises with poor reliability	ICC (SD)	# of exercises with poor reliability	ICC (SD)	# of exercises with poor reliability	ICC (SD)	# of exercises with poor reliability
RMS of pitch displacement	0.38 (0.16)	11	0.50 (0.14)	5	0.39 (0.14)	9	0.40 (0.15)	11
RMS of roll displacement	0.51 (0.17)	4	0.56 (0.19)	4	0.44 (0.16)	8	0.48 (0.17)	7
RMS of pitch velocity	0.58 (0.15)	3	0.60 (0.15)	1	0.47 (0.14)	6	0.55 (0.19)	4
RMS of roll velocity	0.64 (0.12)	1	0.63 (0.19)	3	0.47 (0.14)	8	0.55 (0.17)	4
RMS of AP acceleration	0.46 (0.17)	7	0.53 (0.13)	4	0.40 (0.15)	9	0.40 (0.16)	12
RMS of ML acceleration	0.57 (0.12)	2	0.59 (0.16)	2	0.49 (0.12)	6	0.53 (0.16)	5

RMS: root mean square; AP: anteroposterior; ML: mediolateral; ICC: Intraclass coefficients.

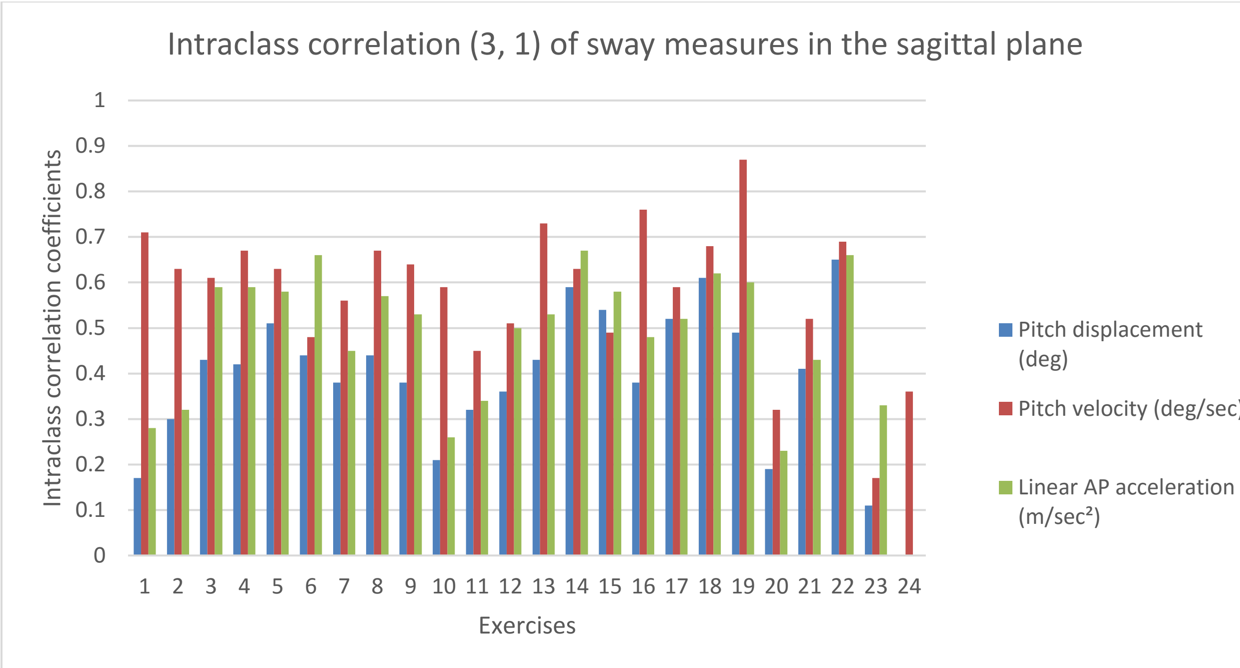


Figure 4-3: Intraclass correlation coefficients, model (3, 1) of sway measures within the 1st visit

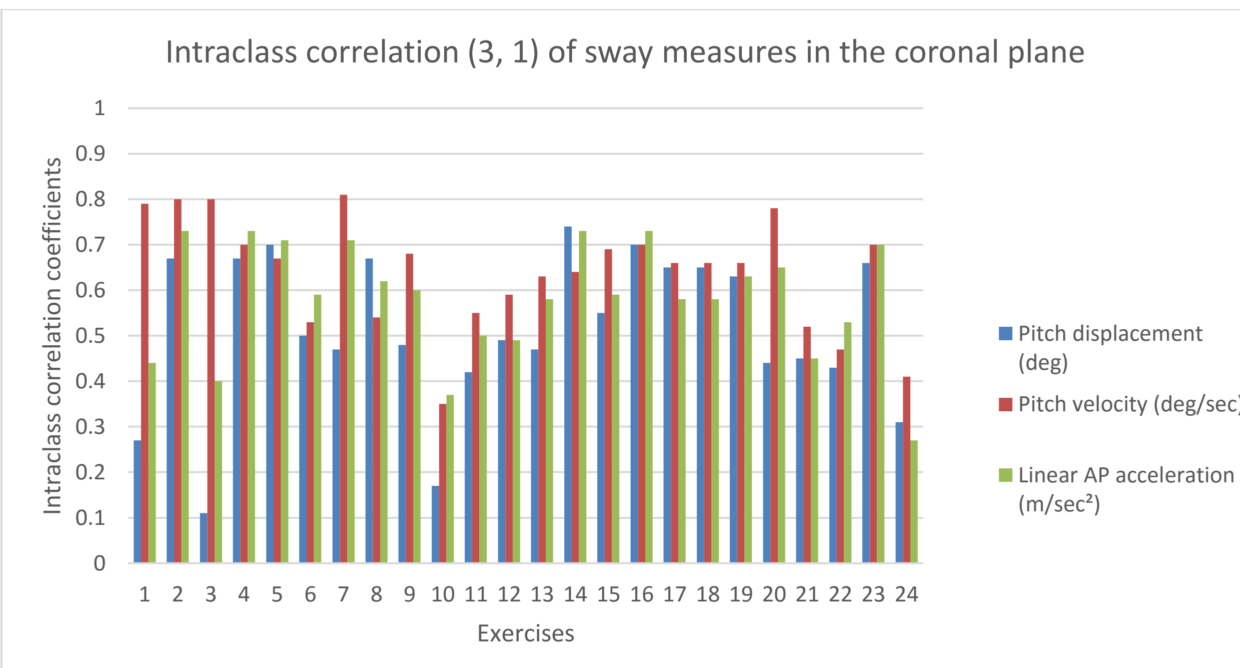


Figure 4-4: Intraclass correlation coefficients, model (3, 1) of sway measures within the 1st visit

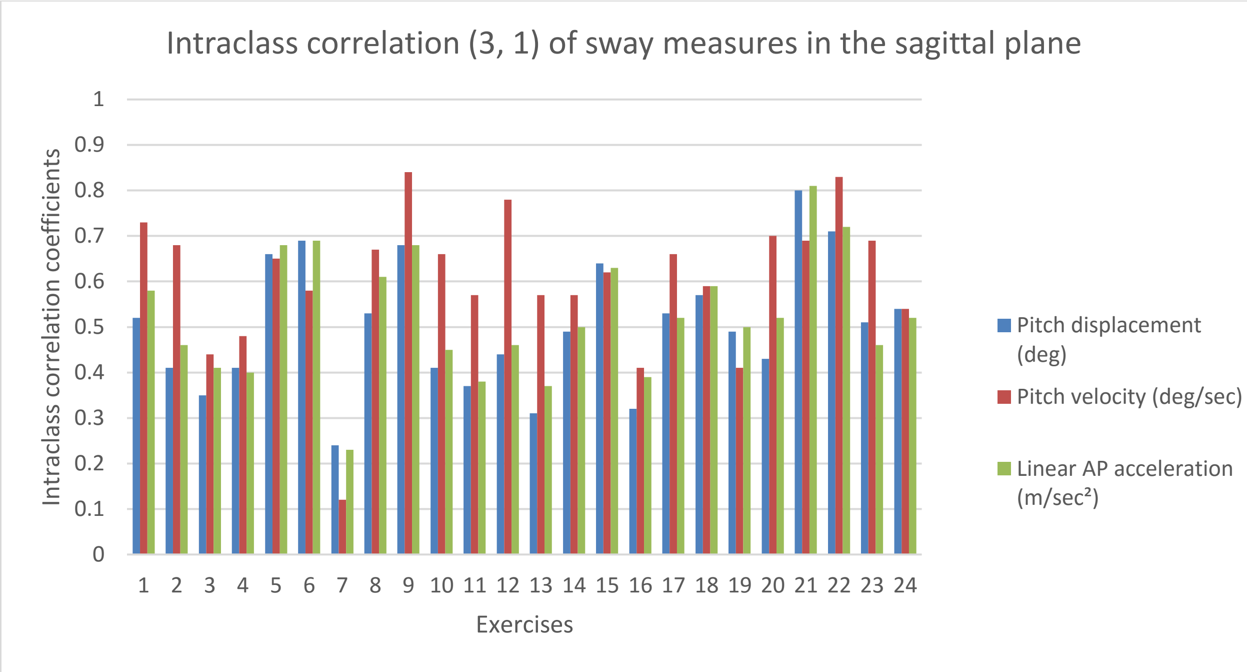


Figure 4-5: Intraclass correlation coefficients, model (3, 1) of sway measures within the 2nd visit

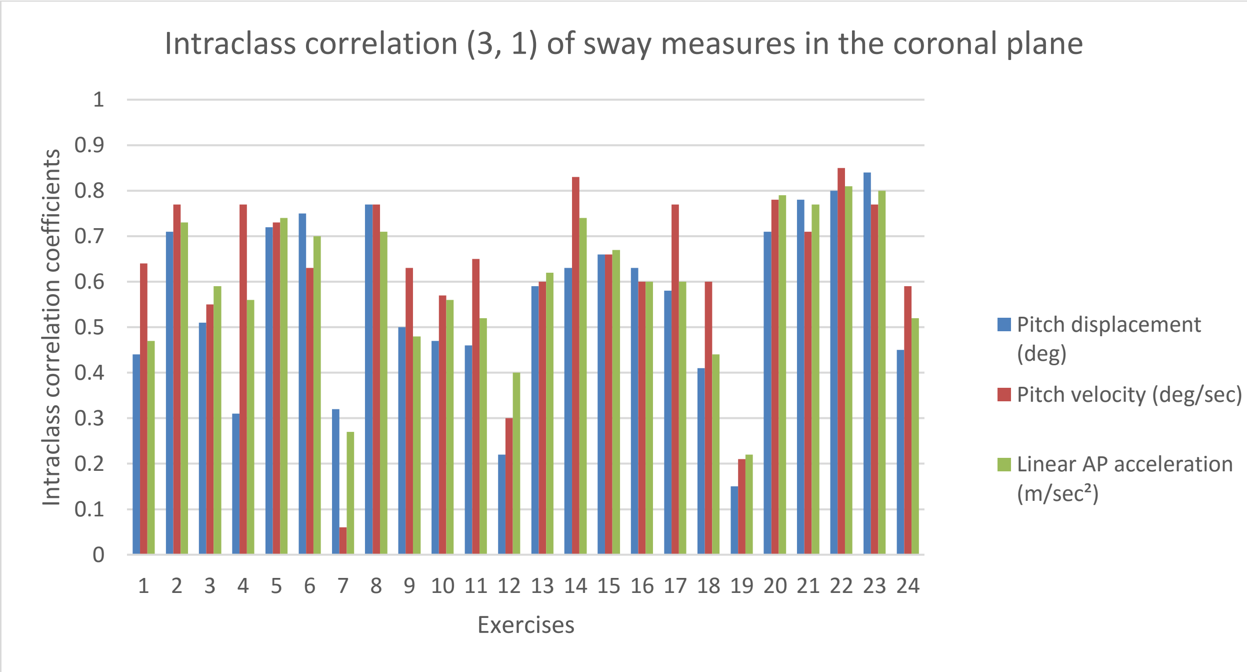


Figure 4-6: Intraclass correlation coefficients, model (3, 1) of sway measures within the 2nd visit

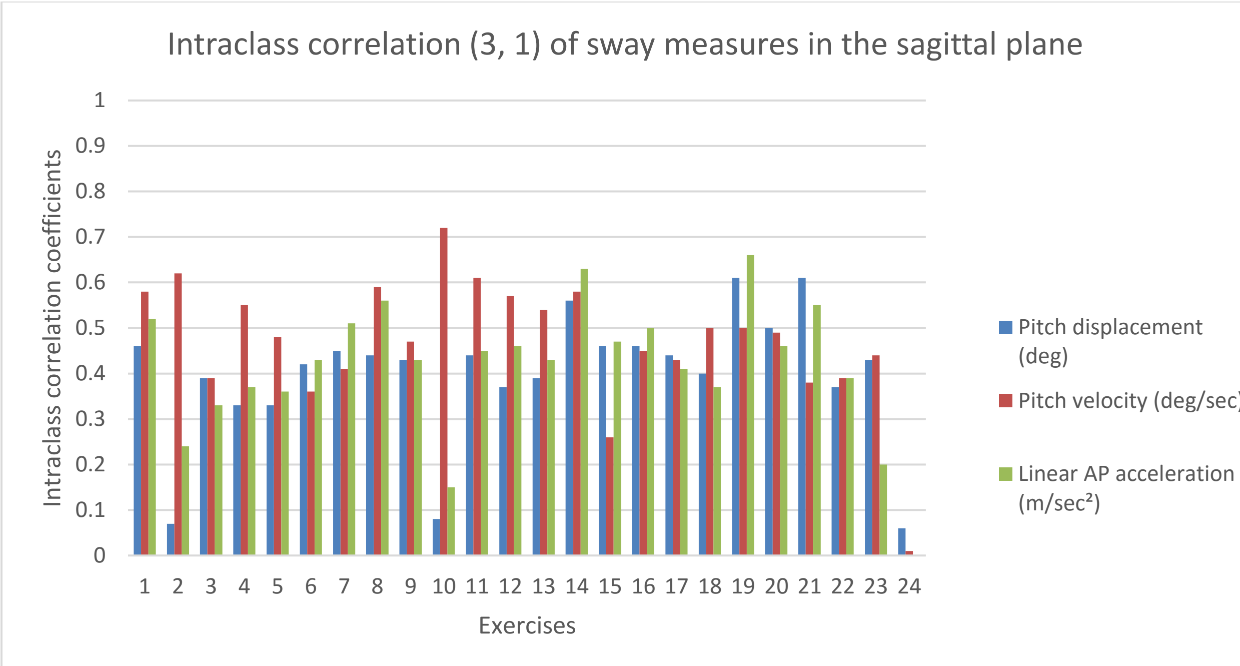


Figure 4-7: Intraclass correlation coefficients, model (3, 1) of sway measures between visits (1st session in 1st visit and 1st session in 2nd visit)

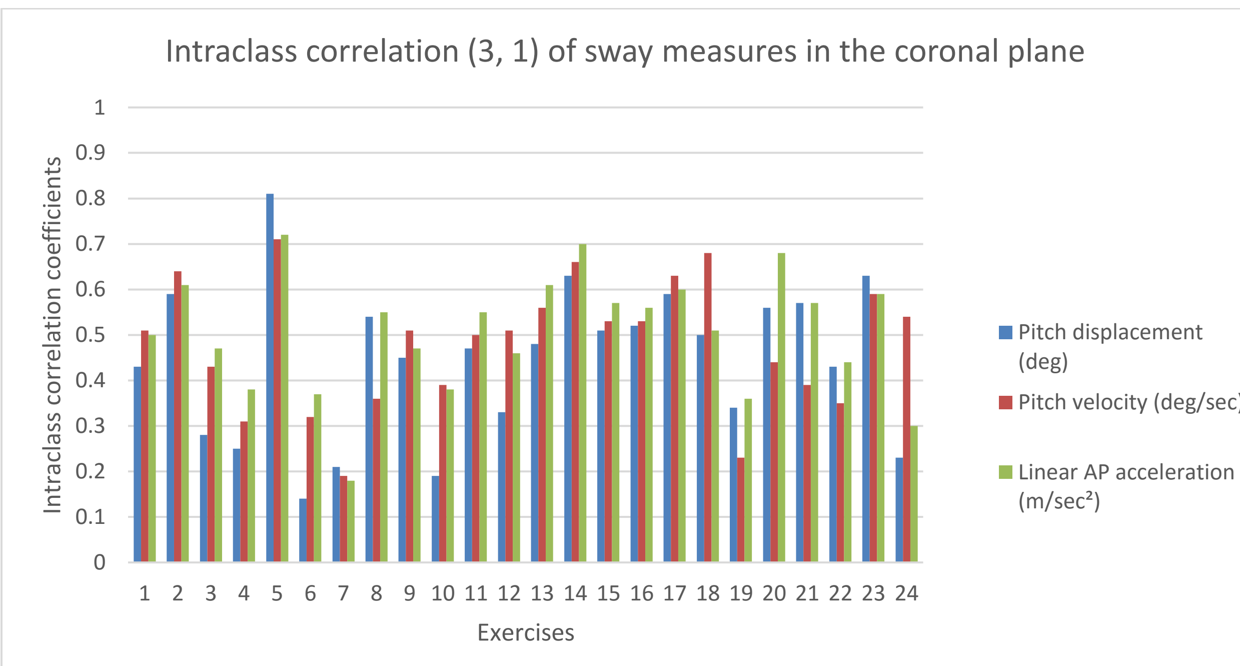


Figure 4-8: Intraclass correlation coefficients, model (3, 1) of sway measures between visits (1st session in 1st visit and 1st session in 2nd visit)

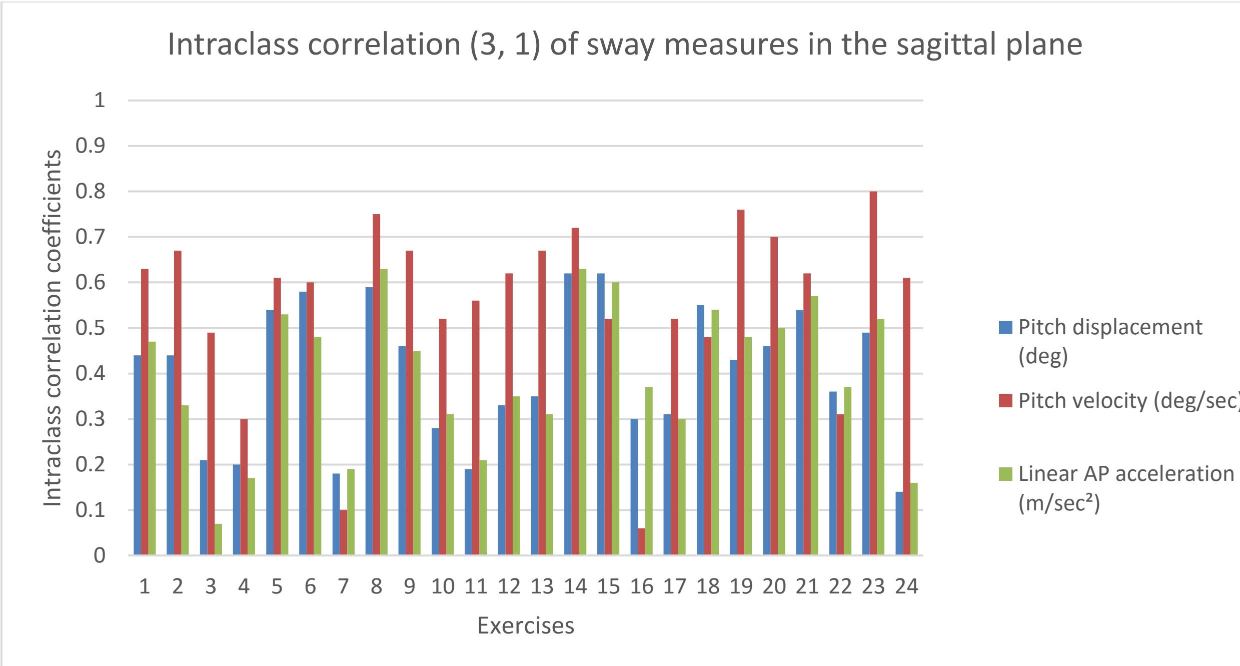


Figure 4-9: Intraclass correlation coefficients, model (3, 1) of sway measures between visits (2nd session in 1st visit and 2nd session in 2nd visit)

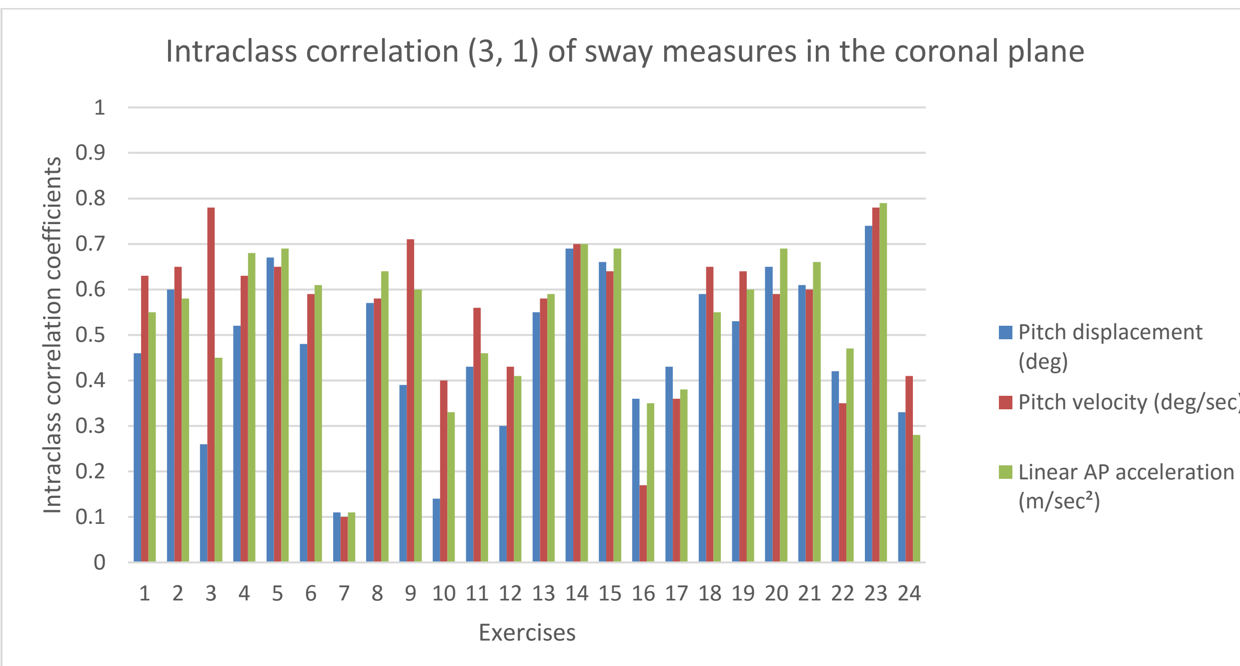


Figure 4-10: Intraclass correlation coefficients, model (3, 1) of sway measures between visits (2nd session in 1st visit and 2nd session in 2nd visit)

The RMS of trunk angular velocity in the pitch and roll directions was the most reliable measure. For this reason, the test-retest reliability, the standard error of measurement (SEM), the minimal detectable change (MDC), and Bland & Altman plots of the trunk angular velocity were explored in detail.

The ICC was good to excellent within the 1st visit (ICC range 0.45-0.87, $p < 0.001$) and within the 2nd visit (ICC range 0.41-0.84, $p < 0.001$) for velocity in the pitch direction for all exercises except three (exercises No. 20 (foam surface, eyes closed, feet apart stance, and yaw head movement), No. 23 (foam surface, eyes closed, semi-tandem stance, and yaw head movement), and No. 24 (foam surface, eyes closed, semi-tandem stance, and pitch head movement)) within the 1st visit and only exercise No. 7 (firm surface, eyes closed, feet apart stance, and head still) within the 2nd visit. Similarly, the ICC was good to excellent within the 1st visit (ICC range 0.47-0.81, $p \leq 0.002$) and within the 2nd visit (ICC range 0.59-0.85, $p < 0.001$) for the velocity of roll direction for all exercises except two exercises (exercises No. 10 (firm surface, eyes closed, semi-tandem stance, and head still), and No. 24) within the 1st visit and three exercises (exercises No. 7, No. 12 (firm surface, eyes closed, semi-tandem stance, and pitch head movement), and No. 19 (foam surface, eyes closed, feet apart stance, and head still)) within the 2nd visit. Conversely, when examining the reliability between visits, the ICC was poor to good between visits (1st session of 1st visit with 1st session of 2nd visit) (ICC ranges 0.01-0.72, $p \leq 0.04$) in the velocity of pitch direction. The exercises that had a poor reliability were numbers No. 3, No. 6, No. 15, No. 21, No. 22, and No. 24. Similarly, the ICC was poor to good between visits (1st session of 1st visit with 1st session of 2nd visit) (ICC ranges 0.23-0.71, $p \leq 0.03$) in the velocity of roll directions.

The exercises that had a poor reliability were numbers No. 4, No. 6, No. 7, No. 8, No. 10, No. 19, No. 21, and No. 23. However, in testing the reliability between visits (2nd session of 1st visit with 2nd session of 2nd visit) the ICC of the RMS pitch velocity was good to excellent except in four exercises (No. 4 (firm surface, eyes open, semi-tandem, head still), No. 22 (foam surface, eyes closed, semi-tandem, and head still), No. 7, and No. 16 (foam surface, eyes open, semi-tandem, and head still)). The ICC of the RMS roll velocity was good to excellent except in four exercises (No. 7, No. 16, No. 17, and No. 22).

Table 4-5: Intraclass correlation coefficients, model (3, 1), SEM, and MDC for trunk tilt velocity within the 1st visit (session 1 and session 2)

Exercises	ICC of RMS of pitch velocity	SD	SEM	MDC	ICC of RMS of roll velocity	SD	SEM	MDC
1	0.71	0.16	0.09	0.24	0.79	0.07	0.03	0.09
2	0.62	0.23	0.14	0.39	0.80	0.49	0.22	0.61
3	0.59	0.94	0.60	1.67	0.80	0.20	0.09	0.25
4	0.67	0.23	0.13	0.37	0.70	0.27	0.15	0.41
5	0.63	0.41	0.25	0.69	0.67	0.58	0.33	0.92
6	0.47	1.15	0.84	2.32	0.53	0.41	0.28	0.78
7	0.56	0.20	0.13	0.37	0.81	0.08	0.03	0.10
8	0.64	0.37	0.22	0.62	0.53	0.74	0.51	1.41
9	0.63	1.21	0.74	2.04	0.68	0.20	0.11	0.31
10	0.59	0.44	0.28	0.78	0.35	0.28	0.23	0.63
11	0.45	0.42	0.31	0.86	0.55	0.57	0.38	1.06
12	0.51	1.30	0.91	2.52	0.59	0.54	0.35	0.96
13	0.73	0.24	0.12	0.35	0.63	0.13	0.08	0.22
14	0.61	0.47	0.29	0.81	0.63	0.55	0.33	0.93
15	0.48	1.07	0.77	2.14	0.67	0.27	0.16	0.43
16	0.75	0.43	0.22	0.60	0.70	0.42	0.23	0.64
17	0.57	0.74	0.49	1.35	0.61	1.03	0.64	1.78
18	0.67	1.41	0.81	2.25	0.66	0.78	0.45	1.26
19	0.87	0.47	0.17	0.47	0.66	0.18	0.10	0.29
20	0.32	0.74	0.61	1.69	0.78	0.66	0.31	0.86
21	0.51	1.04	0.73	2.02	0.51	0.28	0.20	0.54
22	0.70	1.13	0.62	1.72	0.47	0.73	0.53	1.47
23	0.18	0.73	0.66	1.83	0.71	1.72	0.93	2.57
24	0.37	1.38	1.10	3.04	0.43	1.47	1.11	3.08

SEM: Standard Error of Measurement; MDC: Minimum Detectable Change.

Table 4-6: Intraclass correlation coefficients, model (3, 1), SEM, and MDC for trunk tilt velocity within the 2nd visit (session 1 and session 2)

Exercises	ICC of RMS of pitch velocity	SD	SEM	MDC	ICC of RMS of roll velocity	SD	SEM	MDC
1	0.73	0.21	0.11	0.30	0.65	0.08	0.05	0.13
2	0.68	0.25	0.14	0.39	0.78	0.44	0.21	0.57
3	0.44	1.06	0.79	2.20	0.55	0.16	0.11	0.30
4	0.48	0.39	0.28	0.78	0.77	0.16	0.08	0.21
5	0.65	0.53	0.31	0.87	0.73	0.51	0.27	0.73
6	0.58	1.03	0.67	1.85	0.63	0.36	0.22	0.61
7	0.12	0.54	0.51	1.40	0.06	0.17	0.16	0.46
8	0.64	0.34	0.20	0.57	0.77	0.64	0.31	0.85
9	0.83	1.28	0.53	1.46	0.62	0.19	0.12	0.32
10	0.67	0.33	0.19	0.53	0.57	0.17	0.11	0.31
11	0.57	0.68	0.45	1.24	0.65	0.65	0.38	1.07
12	0.78	1.16	0.54	1.51	0.30	0.38	0.32	0.88
13	0.58	0.26	0.17	0.47	0.61	0.14	0.09	0.24
14	0.58	0.44	0.29	0.79	0.83	0.51	0.21	0.58
15	0.63	1.05	0.64	1.77	0.66	0.19	0.11	0.31
16	0.41	0.60	0.46	1.28	0.58	0.58	0.38	1.04
17	0.65	0.79	0.47	1.30	0.76	1.06	0.52	1.44
18	0.59	0.86	0.55	1.53	0.60	0.69	0.44	1.21
19	0.41	0.50	0.38	1.06	0.21	0.24	0.21	0.59
20	0.69	0.53	0.30	0.82	0.79	0.59	0.27	0.75
21	0.69	1.32	0.73	2.04	0.70	0.26	0.14	0.39
22	0.83	1.35	0.56	1.54	0.85	1.18	0.46	1.27
23	0.68	1.22	0.69	1.91	0.77	1.77	0.85	2.35
24	0.55	1.00	0.67	1.86	0.60	1.70	1.08	2.98

SEM: Standard Error of Measurement; MDC: Minimum Detectable Change.

Table 4-7: Intraclass correlation coefficients, model (3, 1), SEM, and MDC for trunk tilt velocity between visits (1st session of 1st visit and 1st session of 2nd visit)

Exercises	ICC of RMS of pitch velocity	SD	SEM	MDC	ICC of RMS of roll velocity	SD	SEM	MDC
1	0.58	0.18	0.12	0.32	0.52	0.08	0.06	0.15
2	0.62	0.27	0.17	0.46	0.63	0.44	0.27	0.74
3	0.38	0.90	0.71	1.96	0.41	0.16	0.12	0.34
4	0.54	0.26	0.18	0.49	0.31	0.22	0.18	0.51
5	0.48	0.44	0.32	0.88	0.71	0.56	0.30	0.84
6	0.35	1.09	0.88	2.44	0.31	0.37	0.31	0.85
7	0.41	0.25	0.19	0.53	0.19	0.08	0.07	0.20
8	0.58	0.41	0.27	0.74	0.34	0.73	0.59	1.64
9	0.47	1.17	0.85	2.36	0.51	0.19	0.13	0.37
10	0.72	0.43	0.23	0.63	0.39	0.27	0.21	0.58
11	0.62	0.54	0.33	0.92	0.50	0.55	0.39	1.08
12	0.55	1.28	0.86	2.38	0.51	0.52	0.36	1.01
13	0.52	0.23	0.16	0.44	0.57	0.13	0.09	0.24
14	0.55	0.47	0.32	0.87	0.65	0.57	0.34	0.93
15	0.26	0.90	0.77	2.15	0.47	0.24	0.17	0.48
16	0.41	0.52	0.40	1.11	0.50	0.58	0.41	1.14
17	0.42	0.75	0.57	1.58	0.59	1.11	0.71	1.97
18	0.51	1.13	0.79	2.19	0.69	0.69	0.38	1.06
19	0.51	0.43	0.30	0.83	0.24	0.24	0.21	0.58
20	0.46	0.61	0.45	1.24	0.42	0.63	0.48	1.33
21	0.38	1.15	0.91	2.51	0.38	0.27	0.21	0.59
22	0.39	0.87	0.68	1.88	0.36	0.87	0.70	1.93
23	0.45	0.63	0.47	1.30	0.58	1.34	0.87	2.41
24	0.01	0.91	0.91	2.51	0.55	1.43	0.96	2.66

SEM: Standard Error of Measurement; MDC: Minimum Detectable Change.

Table 4-8: Intraclass correlation coefficients, model (3, 1), SEM, and MDC for trunk tilt velocity between visits (2nd session of 1st visit and 2nd session of 2nd visit)

Exercises	ICC of RMS of pitch velocity	SD	SEM	MDC	ICC of RMS of roll velocity	SD	SEM	MDC
1	0.62	0.18	0.11	0.31	0.64	0.07	0.04	0.12
2	0.68	0.22	0.12	0.34	0.65	0.46	0.27	0.75
3	0.49	1.06	0.76	2.10	0.78	0.19	0.09	0.25
4	0.29	0.34	0.29	0.79	0.63	0.17	0.10	0.29
5	0.61	0.44	0.27	0.76	0.64	0.54	0.32	0.90
6	0.60	1.05	0.66	1.84	0.59	0.37	0.24	0.66
7	0.10	0.51	0.48	1.34	0.10	0.16	0.15	0.42
8	0.75	0.30	0.15	0.42	0.57	0.55	0.36	1.00
9	0.68	1.19	0.67	1.87	0.69	0.19	0.11	0.29
10	0.53	0.35	0.24	0.67	0.40	0.19	0.15	0.41
11	0.56	0.65	0.43	1.20	0.57	0.64	0.42	1.16
12	0.62	1.12	0.69	1.91	0.42	0.44	0.34	0.93
13	0.66	0.27	0.16	0.44	0.58	0.14	0.09	0.25
14	0.72	0.44	0.23	0.65	0.70	0.47	0.26	0.71
15	0.52	1.08	0.75	2.07	0.60	0.22	0.14	0.39
16	0.06	0.43	0.42	1.16	0.17	0.37	0.34	0.93
17	0.51	0.67	0.47	1.30	0.36	0.85	0.68	1.88
18	0.48	0.88	0.63	1.76	0.65	0.63	0.37	1.03
19	0.76	0.56	0.27	0.76	0.64	0.19	0.11	0.32
20	0.67	0.54	0.31	0.86	0.56	0.58	0.38	1.07
21	0.63	1.11	0.68	1.87	0.58	0.25	0.16	0.45
22	0.31	1.22	1.01	2.81	0.34	0.84	0.68	1.89
23	0.79	1.03	0.47	1.31	0.79	1.79	0.82	2.27
24	0.62	1.28	0.79	2.19	0.42	1.78	1.36	3.76

SEM: Standard Error of Measurement; MDC: Minimum Detectable Change.

The intra-class correlation coefficient (ICC) was calculated to explore the between-day test-retest reliability of the average sway measures from two consecutive trials (averaging the sessions in the 1st visit and the two sessions in the 2nd visit). The scores of the ICC coefficients of all variables (RMS of trunk tilt displacement, velocity, and acceleration) increased substantially after averaging sway measures from two consecutive trials (within visit trials) compared to single trials (see Table 4-9). Mann-Whitney Tests were conducted to evaluate the differences between the ICC coefficients of all variables (RMS of trunk tilt displacement, velocity, and acceleration) after averaging sway measures from two consecutive trials and from single trials. The results of the test indicated a significant increase in the ICC coefficients of all variables (RMS of trunk tilt displacement, velocity, and acceleration) after averaging sway measures from two consecutive trials compared with between-day reliability of single trials.

Table 4-9: The intraclass correlation coefficients, model (3,1), of the RMS of trunk tilt displacement, velocity, and acceleration obtained by averaging 2 trials

Exercise	RMS of pitch displacement	RMS of roll displacement	RMS of pitch velocity	RMS of roll velocity	RMS of AP acceleration	RMS of ML acceleration
1	0.78	0.90	0.73	0.90	0.79	0.90
2	0.75	0.90	0.86	0.87	0.80	0.92
3	0.80	0.89	0.82	0.80	0.82	0.87
4	0.62	0.78	0.78	0.80	0.70	0.79
5	0.71	0.90	0.83	0.92	0.73	0.92
6	0.75	0.96	0.87	0.95	0.79	0.95
7	0.54	0.71	0.74	0.76	0.53	0.80
8	0.86	0.84	0.85	0.89	0.87	0.87
9	0.53	0.70	0.81	0.69	0.64	0.77
10	0.63	0.80	0.79	0.75	0.71	0.85
11	0.66	0.71	0.76	0.68	0.74	0.84
12	0.70	0.88	0.87	0.93	0.75	0.90
13	0.32	0.56	0.52	0.43	0.42	0.66
14	0.84	0.90	0.85	0.92	0.81	0.90
15	0.66	0.74	0.87	0.80	0.73	0.83
16	0.68	0.90	0.76	0.88	0.75	0.92
17	0.72	0.91	0.72	0.89	0.74	0.91
18	0.80	0.87	0.91	0.87	0.83	0.87
19	0.62	0.91	0.84	0.91	0.71	0.92
20	0.72	0.91	0.76	0.89	0.77	0.89
21	0.67	0.87	0.86	0.76	0.74	0.88
22	0.66	0.88	0.84	0.89	0.74	0.93
23	0.70	0.82	0.82	0.93	0.75	0.87
24	0.71	0.81	0.85	0.81	0.77	0.85
Average score	0.68	0.84	0.80	0.83	0.73	0.87

RMS: Root Mean Square; AP: anteroposterior; ML: mediolateral.

Table 4-10: Intraclass correlation coefficients, model (3,1), SEM, and MDC for trunk tilt velocity obtained by averaging 2 trials

Exercises	RMS of pitch velocity	SD	SEM	MDC	RMS of roll velocity	SD	SEM	MDC
1	0.73	1.15	0.60	1.66	0.90	0.78	0.25	0.68
2	0.86	1.05	0.39	1.09	0.87	0.65	0.23	0.65
3	0.82	1.06	0.45	1.25	0.80	0.86	0.38	1.07
4	0.78	0.73	0.34	0.95	0.80	0.64	0.29	0.79
5	0.83	1.06	0.44	1.21	0.92	0.73	0.21	0.57
6	0.87	1.05	0.38	1.05	0.95	1.19	0.27	0.74
7	0.74	1.15	0.59	1.63	0.76	0.72	0.35	0.98
8	0.85	0.96	0.37	1.03	0.89	0.50	0.17	0.46
9	0.81	0.78	0.34	0.94	0.69	0.55	0.31	0.85
10	0.79	0.92	0.42	1.17	0.75	0.73	0.37	1.01
11	0.76	1.09	0.53	1.48	0.68	0.75	0.42	1.18
12	0.87	1.07	0.39	1.07	0.93	0.88	0.23	0.65
13	0.52	1.19	0.82	2.29	0.43	0.75	0.57	1.57
14	0.85	1.05	0.41	1.13	0.92	0.54	0.15	0.42
15	0.87	0.97	0.35	0.97	0.80	0.68	0.30	0.84
16	0.76	0.89	0.44	1.21	0.88	0.83	0.29	0.80
17	0.72	1.16	0.61	1.70	0.89	0.81	0.27	0.74
18	0.91	0.99	0.30	0.82	0.87	0.67	0.24	0.67
19	0.84	0.89	0.36	0.99	0.91	0.70	0.21	0.58
20	0.76	1.25	0.61	1.70	0.89	1.14	0.38	1.05
21	0.86	1.06	0.40	1.10	0.76	0.75	0.37	1.02
22	0.84	0.86	0.34	0.95	0.89	0.72	0.24	0.66
23	0.82	1.03	0.44	1.21	0.93	0.74	0.20	0.54
24	0.85	1.10	0.43	1.18	0.81	0.81	0.35	0.98

SEM: Standard Error of Measurement; MDC: Minimum Detectable Change.

Bland-Altman plots were examined to see if there was a relationship between the amount of difference and the average of the trunk tilt velocity in the pitch and roll directions from trial 1 and 2 within the 1st visit. For most exercises, there was an obvious relationship between the difference and the average of the two times of the measurement, where the difference between the two trials tended to increase with the increase in the mean scores of the two trials (e.g. exercises No. 7, No. 14, and No. 20) (Figures 4-12, 4-14, and 4-15). For some exercises, the difference scores were distributed evenly across the mean scores (e.g. exercises No. 1 and No. 8) (Figures 4-11 and 4-13), whereas there were not enough subjects who could complete exercise No. 23 making comparison impossible (Figure 4-16).

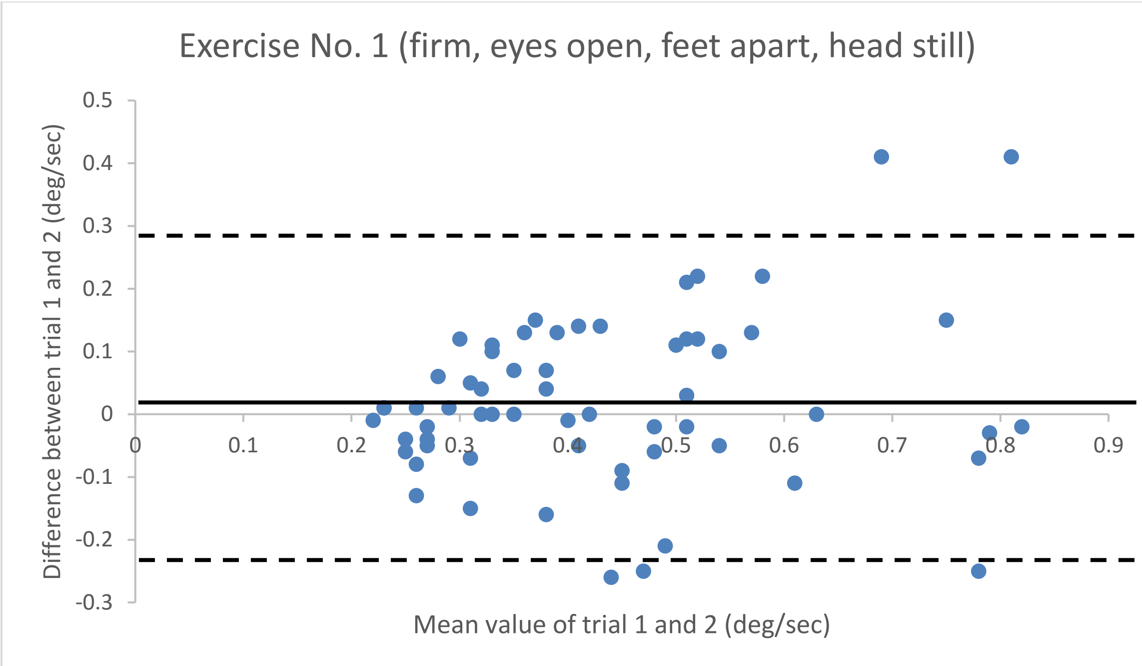


Figure 4-11: Bland-Altman plot representing comparisons between velocity of trunk tilt in the pitch direction in trial 1 and 2 within the 1st visit for exercise 1. Solid line indicates the mean difference. Dotted lines indicate the limits of agreement ($\pm$ 2 SD).

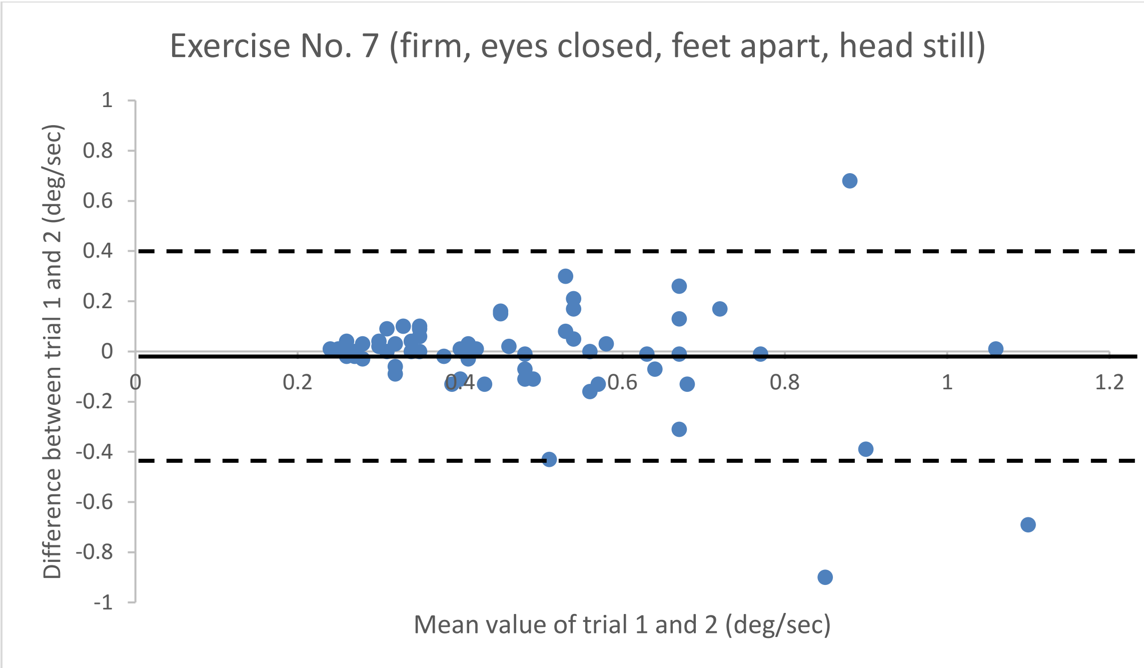


Figure 4-12: Bland-Altman plot representing comparisons between velocity of trunk tilt in the pitch direction in trial 1 and 2 within the 1st visit for exercise 7. Solid line indicates the mean difference. Dotted lines indicate the limits of agreement (± 2 SD).

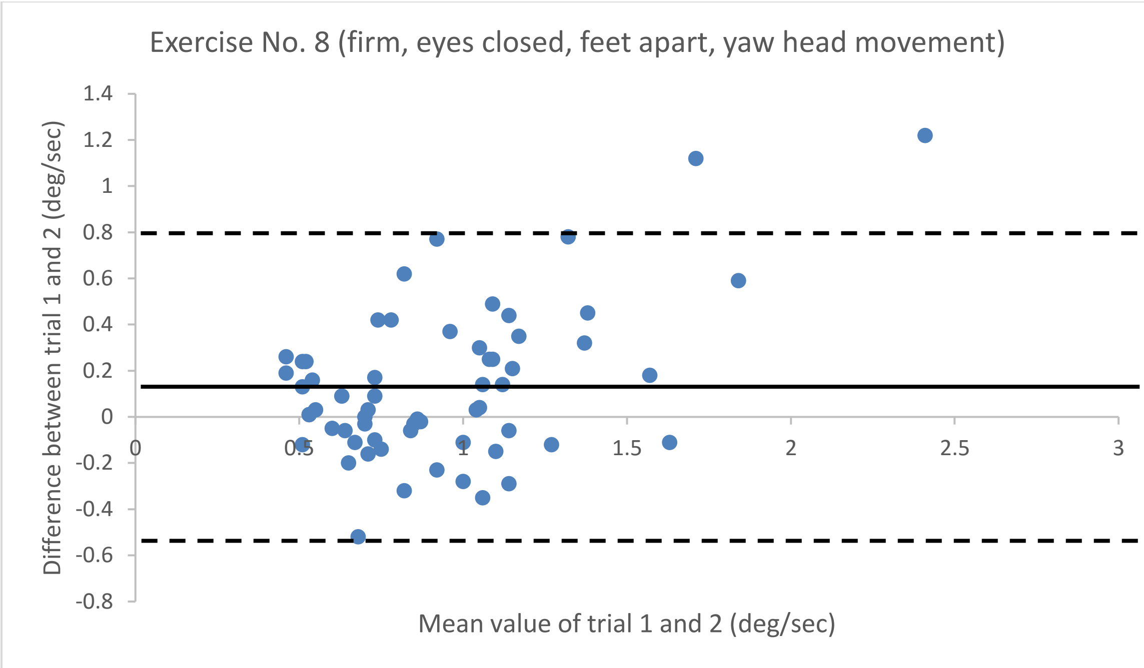


Figure 4-13: Bland-Altman plot representing comparisons between velocity of trunk tilt in the pitch direction in trial 1 and 2 within the 1st visit for exercise 18. Solid line indicates the mean difference. Dotted lines indicate the limits of agreement (± 2 SD).

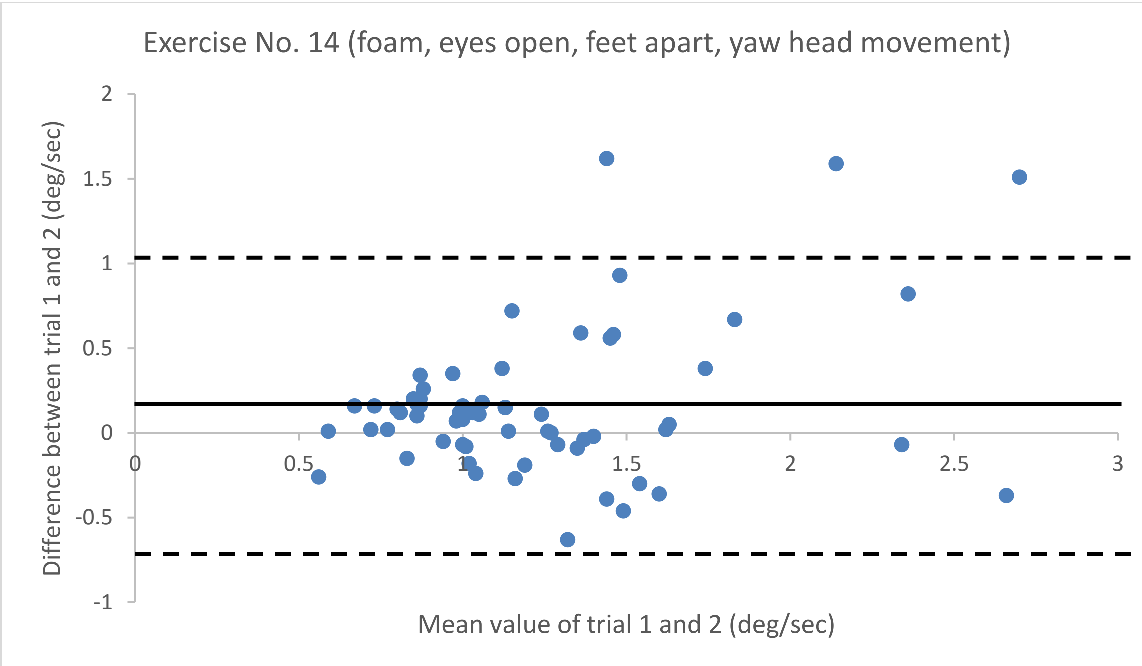


Figure 4-14: Bland-Altman plot representing comparisons between velocity of trunk tilt in the pitch direction in trial 1 and 2 within the 1st visit for exercise 14. Solid line indicates the mean difference. Dotted lines indicate the limits of agreement (± 2 SD).

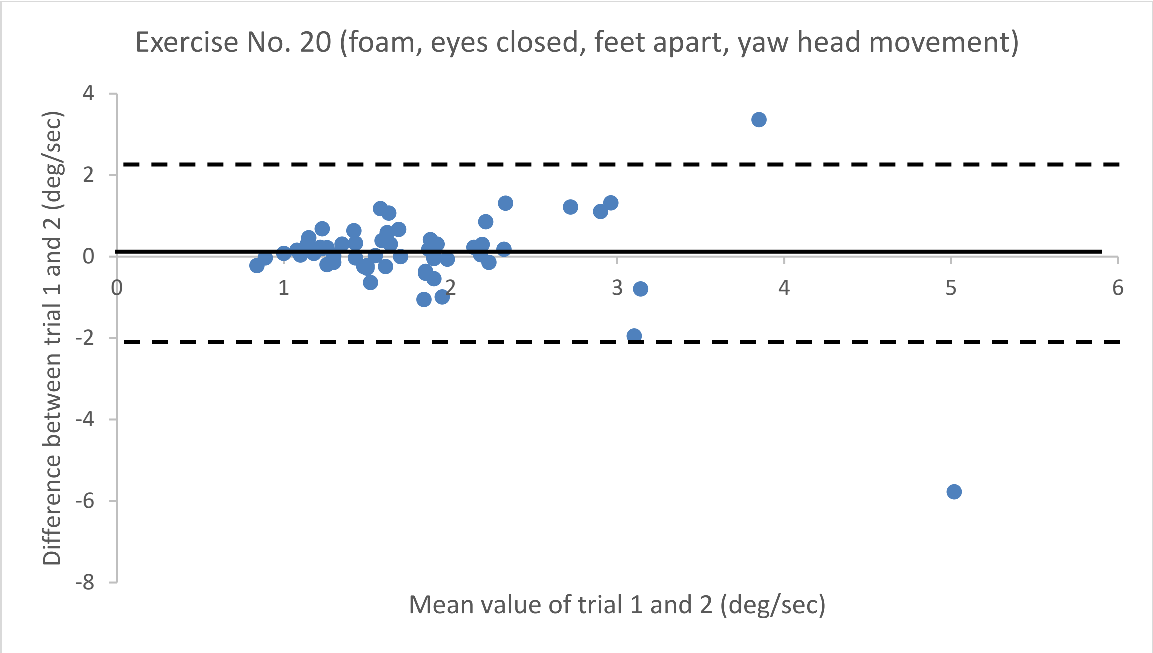


Figure 4-15: Bland-Altman plot representing comparisons between velocity of trunk tilt in the pitch direction in trial 1 and 2 within the 1st visit for exercise 20. Solid line indicates the mean difference. Dotted lines indicate the limits of agreement (± 2 SD).

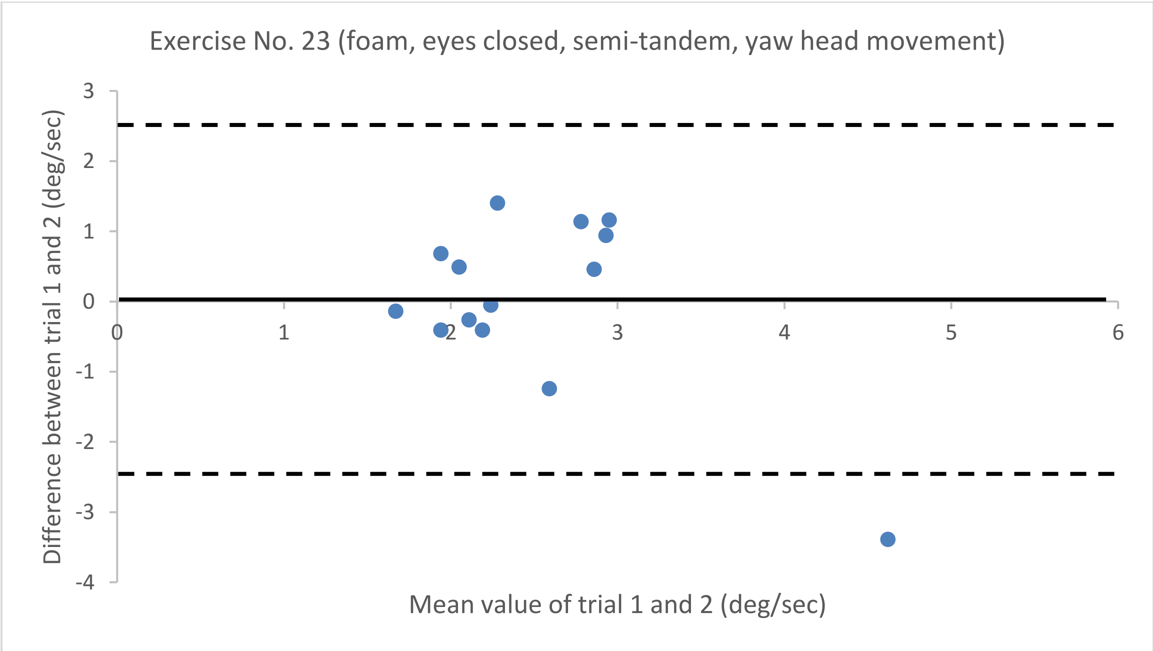


Figure 4-16: Bland-Altman plot representing comparisons between velocity of trunk tilt in the pitch direction in trial 1 and 2 within the 1st visit for exercise 23. Solid line indicates the mean difference. Dotted lines indicate the limits of agreement (± 2 SD).

Weighted kappa (linear weights) was used to explore the agreement of healthy subjects' rating of perceived difficulty of 24 static stance balance exercises within and between two visits occurring one week apart. Weighted kappa scores for scale A were fair to substantial (0.32 – 0.68, $p < .001$) for the rating of perceived difficulty of all exercises performed over two times within the 1st visit and within the 2nd visit (Table 4-11). Weighted kappa scores for scale A was fair to moderate (0.34 – 0.60, $p < .001$) for the rating of perceived difficulty of all exercises compared between visits (1st session of 1st visit with 1st session of 2nd visit and 2nd session of 1st visit with 2nd session of 2nd visit) except exercise # 23 which had poor agreement (see Table 4-11).

Table 4-11: Weighted kappa (linear weights) coefficients for Scale A

Exercise	Within visits		Between visits	
	Scale A T1&T2	Scale A T3&T4	Scale A T1&T3	Scale A T2&T4
1	0.60	0.58	0.43	0.60
2	0.57	0.56	0.40	0.57
3	0.50	0.56	0.46	0.47
4	0.43	0.55	0.47	0.44
5	0.48	0.62	0.41	0.50
6	0.52	0.54	0.48	0.45
7	0.56	0.68	0.54	0.44
8	0.48	0.60	0.42	0.46
9	0.54	0.58	0.37	0.57
10	0.34	0.56	0.40	0.48
11	0.45	0.43	0.49	0.44
12	0.51	0.56	0.39	0.51
13	0.43	0.53	0.35	0.47
14	0.45	0.53	0.37	0.37
15	0.32	0.48	0.34	0.42
16	0.39	0.57	0.36	0.50
17	0.47	0.56	0.50	0.49
18	0.57	0.41	0.35	0.52
19	0.44	0.55	0.39	0.57
20	0.49	0.53	0.36	0.56
21	0.47	0.50	0.42	0.38
22	0.43	0.59	0.45	0.49
23	0.37	0.49	0.42	0.18
24	0.39	0.58	0.48	0.57
Average	0.47	0.55	0.42	0.48

T1: trial 1; T2: trial 2; T3: trial 3; T4: trial 4.

Weighted kappa scores for scale B were fair to substantial (0.21 – 0.74, $p < .05$) for the rating of perceived difficulty of all exercises performed over two times within the 1st visit and the 2nd visit except exercise No. 1 (firm surface, eyes open, feet apart, and head still). Similarly, weighted kappa scores for scale B were fair to substantial (0.28 – 0.69, $p < .05$) for the rating of perceived difficulty of all exercises compared between visits (1st session of 1st visit with 1st session of 2nd visit and 2nd session of 1st visit with 2nd session of 2nd visit) except exercises No. 1 and 3 (firm surface, eyes open, feet apart, and pitch head movement) (see Table 4-12).

Table 4-12: Weighted kappa (linear weights) coefficients for Scale B

Exercise	Within visits		Between visits	
	Scale B T1&T2	Scale B T3&T4	Scale B T1&T3	Scale B T2&T4
1	-0.03	0.38	-0.04	0.48
2	0.64	0.46	0.28	0.64
3	0.21	0.52	0.14	0.46
4	0.43	0.47	0.51	0.44
5	0.65	0.55	0.44	0.44
6	0.55	0.47	0.61	0.42
7	0.42	0.47	0.54	0.55
8	0.33	0.74	0.65	0.46
9	0.31	0.48	0.40	0.54
10	0.35	0.44	0.36	0.50
11	0.38	0.32	0.49	0.57
12	0.42	0.55	0.38	0.42
13	0.49	0.59	0.39	0.61
14	0.56	0.50	0.34	0.44
15	0.38	0.51	0.42	0.36
16	0.39	0.49	0.40	0.53
17	0.39	0.58	0.46	0.31
18	0.38	0.39	0.49	0.35
19	0.34	0.60	0.26	0.69
20	0.37	0.55	0.46	0.42
21	0.45	0.52	0.43	0.47
22	0.38	0.58	0.46	0.41
23	0.42	0.38	0.43	0.33
24	0.28	0.36	0.44	0.30
Average	0.40	0.50	0.41	0.46

T1: trial 1; T2: trial 2; T3: trial 3; T4: trial 4.

On average, Scale A had higher agreement scores compared to Scale B, while the highest average score of agreement was within visits compared to between visits. On the other hand, forty-one subjects out of 62 (66.1%) reported that they liked scale B more than Scale A, where many of the participants pointed out that the statements in scale B described how they felt.

The intra-class correlation coefficient (ICC model (3, 1)) was computed to explore the test-retest reliability of the IRT-converted scores of scale B. The reliability of subjects' rating of all exercises reached excellent reliability within and between visits (see Table 4-13).

Table 4-13: The intraclass correlation coefficients (ICC) of the converted scores of Scale B

Exercise	Within visits		Between visits	
	Scale B T1&T2	Scale B T3&T4	Scale B T1&T3	Scale B T2&T4
	ICC of IRT scores	ICC of IRT scores	ICC of IRT scores	ICC of IRT scores
1	0.957	0.982	0.941	0.966
2	0.963	0.958	0.946	0.941
3	0.966	0.980	0.941	0.960
4	0.969	0.950	0.953	0.935
5	0.960	0.982	0.942	0.961
6	0.968	0.960	0.948	0.940
7	0.968	0.982	0.943	0.957
8	0.966	0.970	0.957	0.955
9	0.971	0.985	0.960	0.969
10	0.959	0.964	0.939	0.953
11	0.964	0.983	0.949	0.961
12	0.960	0.980	0.938	0.970
13	0.957	0.984	0.935	0.966
14	0.965	0.948	0.944	0.937
15	0.964	0.986	0.938	0.964
16	0.963	0.965	0.950	0.951
17	0.957	0.983	0.934	0.958
18	0.968	0.953	0.944	0.939
19	0.969	0.981	0.950	0.960
20	0.967	0.976	0.959	0.965
21	0.963	0.982	0.949	0.962
22	0.959	0.978	0.938	0.969
23	0.965	0.979	0.951	0.966
24	0.955	0.972	0.940	0.959

T1: trial 1; T2: trial 2; T3: trial 3; T4: trial 4.

4.3.3 Concurrent validity

Multiple regression analysis was used to assess the association between the scores of the rating of perceived difficulty scales and the postural sway measures during the performance of the balance exercises (Bland & Altman, 1995). Overall, for all age groups, the correlation coefficients were relatively similar between scale A and B, and the correlations between the rating of perceived difficulty and RMS trunk linear acceleration were the highest followed by angular displacement, and then RMS trunk tilt velocity. Additionally, the correlations between the ratings of perceived difficulty and the sway measures in the roll direction were higher compared with the pitch direction.

There were strong, positive correlations between the rating of perceived difficulty scales (A and B) and RMS trunk tilt acceleration in the ML direction in the young and middle aged groups (r = 0.75-0.77, $p < .001$), moderate, positive correlations in the old groups (r = 0.70-0.72, $p < .001$), and in the very old group (r = 0.64-0.66, $p < .001$). There were moderate, positive correlations between the rating of perceived difficulty scales (A and B) and RMS of trunk tilt acceleration in the AP direction for all age groups (Scale A r = 0.51-0.64, $p < .001$; Scale B r = 0.54-0.62, $p < .001$).

There were moderate, positive correlations between the rating of perceived difficulty scales (A and B) and RMS of trunk tilt displacement and velocity in the AP and ML directions in all age groups (r = 0.40-0.73, $p < .001$) except between the rating of perceived difficulty scale B and RMS of trunk tilt velocity in the AP direction in the young and old groups (Table 4-14 and 4-15).

Table 4-14: Results of the regression analysis of Scale A and RMS of trunk tilt sway

Groups	RMS of pitch displacement	RMS of roll displacement	RMS of pitch velocity	RMS of roll velocity	RMS of AP acceleration	RMS of ML acceleration
Young (18-44)	0.53	0.72	0.40	0.71	0.59	0.77
Middle aged (45-59)	0.62	0.73	0.48	0.68	0.64	0.77
Old (60-74)	0.55	0.69	0.40	0.59	0.56	0.70
Very old (75-85)	0.49	0.63	0.48	0.58	0.51	0.64
All groups (18-85)	0.54	0.69	0.43	0.64	0.57	0.72

RMS: Root Mean Square; AP: anteroposterior; ML: mediolateral.

Table 4-15: Results of the regression analysis of Scale B and RMS of trunk tilt sway

Groups	RMS of pitch displacement	RMS of roll displacement	RMS of pitch velocity	RMS of roll velocity	RMS of AP acceleration	RMS of ML acceleration
Young (18-44)	0.53	0.71	0.37	0.69	0.56	0.75
Middle aged (45-59)	0.59	0.72	0.44	0.67	0.62	0.76
Old (60-74)	0.56	0.71	0.39	0.60	0.56	0.72
Very old (75-85)	0.53	0.67	0.51	0.60	0.54	0.66
All groups (18-85)	0.55	0.70	0.42	0.64	0.57	0.72

RMS: Root Mean Square; AP: anteroposterior; ML: mediolateral.

Additional multiple regression analyses were performed to assess the relationship between postural sway measures and scores of scale B, which were converted from ordinal values to continuous values using the IRT method. The correlation coefficients of converted scores of Scale B and the RMS of trunk tilt sway changed slightly within a small range (± 0.06) compared with the correlation coefficients of Scale B and RMS of trunk tilt sway (see Table 4-16).

Table 4-16: Results of the regression analysis of converted scores of Scale B and RMS of trunk tilt sway

Groups	RMS of pitch displacement	RMS of roll displacement	RMS of pitch velocity	RMS of roll velocity	RMS of AP acceleration	RMS of ML acceleration
Young (18-44)	0.53	0.69	0.36	0.63	0.57	0.74
Middle aged (45-59)	0.59	0.71	0.43	0.65	0.62	0.77
Old (60-74)	0.56	0.70	0.42	0.60	0.58	0.73
Very old (75-85)	0.51	0.70	0.50	0.61	0.54	0.71
All groups (18-85)	0.53	0.70	0.42	0.62	0.57	0.74

RMS: Root Mean Square; AP: anteroposterior; ML: mediolateral.

4.4 DISCUSSION

In this study, the test-retest reliability of the subjects' performance during static standing balance exercises and their rating of perceived difficulty of standing balance exercises was examined, and the two scales of rating of perceived difficulty of balance exercises were validated by comparing the scales with quantitative sway measures. The results demonstrated that the subjects' balance performance had at least good reliability with few exceptions. On average, Scale A had relatively higher agreement scores compared to Scale B. In addition, the two scales (Scale A and B) of ratings of perceived difficulty of balance exercises are valid and showed relatively similar validity scores. However, 66% of the subjects reported that they liked scale B more than Scale A.

Test-retest reliability (postural sway):

The mean scores of the ICC coefficients of RMS of trunk tilt velocity were higher than the average scores of the coefficients of RMS of trunk tilt acceleration and displacement.

Consistently, several studies have examined the reliability of sway measures during different postural control tasks in different age populations and found that the mean velocity is the most reliable measure of postural sway (Benvenuti et al., 1999; Doyle, Hsiao-Wecksler, Ragan, & Rosengren, 2007; Hertel, Olmsted-Kramer, & Challis, 2006; Lafond, Corriveau, Hebert, & Prince, 2004; Rafal, Janusz, Wieslaw, & Robert, 2011; Swanenburg, de Bruin, Favero, Uebelhart, & Mulder, 2008). Rafal et al. assessed the reliability of 27 elderly subjects' performance during static standing on a force plate and found that the mean velocity of center of pressure (COP) provided the highest reliability within and between visits, compared with the range in the anterior-posterior and medio-lateral directions, and 95th percentile confidence ellipse area (Rafal, Janusz, Wieslaw, & Robert, 2011). Similarly, a systematic review that included thirty-two studies revealed that among all other COP measures, the velocity measure was generally a good reliable measure (Ruhe, Fejer, & Walker, 2010). In the inverted pendulum model of postural control, the COP is related to the body tilt displacement of the center of mass (COM) in the following way. The displacement of the COP, which reflects the torque output of the ankle effectors, causes the inverted pendulum to move, which is represented by the body tilt and translation of the COM.(D. A. Winter, 1995) The COP displacement typically leads the COM translation, and mathematically, the difference between the COP and COM displacement is proportional to the acceleration of the COM. A possible biomechanical explanation for tilt velocity being the most reliable measure might be that body tilt displacement is more prone to drift (for example going from a forward lean to a backward lean) and thus have more variation from trial to trial despite a person having stable posture. On the other hand, the body tilt velocity should have no drift over time, and thus the RMS value would be more consistent.

Despite the report of good reliability of COP measurements, there are a limited number of studies that have assessed the reliability of postural sway measures using an accelerometer-based sensor. One study by Whitney et al. assessed the reliability of COP measures using a force plate and normalized path length of the accelerometer and found that the reliability of the accelerometer was either similar or better than the COP measures (Whitney et al., 2011).

The results of the intra-class correlation coefficient (ICC) of the sway measures (trunk angular displacement and velocity, and linear acceleration) within and between visits showed that the sway measures in the roll direction were more reliable in more exercises compared to sway measures in the pitch direction. The limited base of support in mediolateral direction especially during semi-tandem stance exercises compared to the anteroposterior direction may have produced greater variability in the amount of sway which may explain the higher reliability of sway measures in the ML direction. Others have noted that sway measures in the mediolateral direction were more reliable compared to sway measures in the anteroposterior direction (Goldie, Bach, & Evans, 1989; Heebner, Akins, Lephart, & Sell, 2015; Moe-Nilssen, 1998; Rafal et al., 2011; Swanenburg et al., 2008). These studies have reached the same conclusion that the mediolateral direction is more reliable despite different instrumentation and populations utilized. Swanenburg et al. recruited 37 older adults, of whom 11 had a history of falling, to investigate the reliability of their balance performance during static standing using a force platform and found that the ICC values were higher in the mediolateral direction compared to the ICC values in the anteroposterior direction (Swanenburg et al., 2008). Others have reached the same conclusion when they studied 10 healthy young adults to calculate the reliability of their postural stability using an accelerometer during static and dynamic exercises (Heebner et al., 2015). Additionally, sway measures in the mediolateral direction were the only measures able to show a significant difference between static exercises, while sway measures in all directions showed differences between static and dynamic exercises (Heebner et al., 2015). Based on these findings, we recommend the inclusion of sway measures in the mediolateral direction, especially the velocity measure when conducting studies that compare between groups or assess the reliability of performance during standing balance exercises.

Overall, this study determined that test-retest reliability coefficients of sway measures within visits (intra-sessions) appear to have higher reliability values compared to between visits (inter-sessions), which is consistent with previous studies (Benvenuti et al., 1999; D. Lin, Seol, Nussbaum, & Madigan, 2008; Rafal et al., 2011). This conclusion was also supported by the results of the ratings of perceived difficulty agreement testing, in which the scores of agreement where higher within visits compared to between visits. Although a number of studies have agreed upon that test-retest reliability coefficients of sway measures within visits have higher reliability values compared to between visits, they did not attribute this disparity in reliability values between intra and inter-sessions to an apparent reason. Several studies proposed that this difference in test-retest reliability coefficients may be attributed to a change in postural control over time (D. Lin et al., 2008; Tjernstrom, Fransson, Hafstrom, & Magnusson, 2002), whereas Fisher attributed the disparity in reliability scores to biological reasons such as stress of daily life that cannot be controlled (Fisher, 2010).

Averaging two consecutive trials within visits increased the ICC coefficients substantially for all variables compared to the ICC coefficients obtained from a single trial. The inherent variability in maintaining equilibrium may explain the lower reliability coefficients calculated from a single trial compared to averaging two trials for all exercises. Additionally, averaging sway measures from two trials or more leads to a better estimate of the true value which may explain the improvement of the ICC coefficients after averaging. Studies have been designed to determine the appropriate number of trials to be averaged in order to obtain reliable measures and concluded that averaging sway measures from at least two trials can improve the reliability coefficients, especially the velocity measure (Corriveau, Hebert, Prince, & Raiche, 2000; Hufschmidt, Dichgans, Mauritz, & Hufschmidt, 1980; Lafond et al., 2004; Ruhe et al., 2010). Lafond et al. recommended averaging two trials to obtain a reliable measure (ICC > 0.90) of the COP mean velocity and averaging 4 trials was needed to obtain a reliable measure of the COP range and displacement (Lafond et al., 2004). Additionally, Lafond et al. assessed the reliability of sway measures of different time lengths (30, 60, and 120 seconds) and found that the ICC values increased with longer test durations. In light of our study's results, it is recommended to average sway measures from two trials in order to obtain reliable results especially for the velocity measure, while other measures may need averaging from more than two trials to get reliable results. Additionally, we recommend using trials of a longer time as permitted by the patients' health status to obtain higher reliability scores according to results of other studies (Lafond et al., 2004).

Test-retest reliability (ratings of perceived difficulty):

The weighted kappa individual scores for Scale A were fair to substantial within visits and fair to moderate between visits whereas the scores for Scale B were fair to substantial within and between visits with some exceptions. However, the overall average scores of agreement were higher for Scale A. Scale B is considered a short scale with five levels compared to Scale A which has 11 levels. Shorter scales tend to have a prevalence effect compared to longer scales, which associates inversely with the magnitude of kappa coefficients (Sim & Wright, 2005). The prevalence effect is present when there is a huge difference in the proportion of the agreement between the different levels of the classification (Sim & Wright, 2005). For instance, in a situation where raters choose between 2 classifying cases like positive or negative or even more cases like hard, medium, and easy, a prevalence effect exists when the agreements on one classification is extremely higher than other classifications. With an increase in the prevalence effect, the chance agreement will increase, but the kappa coefficient will decrease accordingly. However, prevalence effects were evident in some of the exercise intra-rater ratings in Scale B, which may explain why Scale B had lower agreement scores on average compared to Scale A.

Concurrent validity:

The correlation coefficients between ratings of perceived difficulty scales (A and B) and the sway measures ranged between moderate to strong in measures calculated in the ML direction and were moderate in the AP direction with a few exceptions in the correlation coefficients of Scale B and pitch angular velocity. These moderate to strong correlation coefficients demonstrate a concurrent validity of the two rating scales which confirms our hypothesis in this study.

The level of correlations between the sway measures and the rating of perceived difficulty was different between the AP and ML directions indicating higher correlation scores for the ML direction. This difference suggests that subjects may have based their rating of perceived difficulty on their perception of sway in the medial-lateral direction. Maki et al. found that poor control of lateral stability is correlated with future falls (Maki et al., 1994). The limited base of support in the mediolateral direction compared to the anteroposterior direction may have produced a greater amount of sway, which may explain the strong relationship between the sway measures and the rating of perceived difficulty in the ML direction.

The results of this study demonstrated that the intra-rater agreement testing of the rating of perceived difficulty scales (Scales A and B) had at least fair to substantial agreement with few exceptions, and possessed concurrent validity with sway measures. The rating scales are easy to use and interpret in clinical settings compared to technology-based techniques to assess postural sway. In regards to Farlie et al.'s systematic review that included thirty-two studies of balance interventions that did not find a single valid instrument to measure intensity of balance exercises (Farlie et al., 2013), we believe that clinicians can use the ratings of perceived difficulty scales as a proxy measure of the intensity of the balance exercise and progress the patient to the next level of intensity in cases where measuring sway is not possible.

The static standing balance exercises that were studied are commonly prescribed in the clinic, and encompass a wide variety of conditions that are used in vestibular rehabilitation. However, some exercises had poor sway reliability. After reviewing the average value of sway measures and rating of perceived difficulty scores for these exercises as well as the missing values of the balance and vestibular exercises, it became clear that some of the exercises with low reliability coefficients were relatively easy exercises, resulting in limited variability which may explain the poor reliability. Other exercises with low reliability were very difficult exercises in which subjects, especially older subjects, couldn't maintain their balance throughout these exercises, resulting in a greater proportion of missing data for those exercises. Furthermore, only subjects with good balance, which we expect to have less variability in sway, were able to maintain their balance throughout those exercises. In addition, a few exercises (1, 3, and 23) had poor kappa scores in Scale B. Upon reviewing the proportions of agreement on the different classifications (1-5) of Scale B for those exercises, a prevalence effect was evident in which there was a large difference in the proportion of the agreement between the different classifications of Scale B for exercises 1, 3, and 23, which may explain why those exercises had low agreement scores (Sim & Wright, 2005).

4.5 LIMITATIONS

The experimental visits in this study lasted for one hour and forty-five minutes on average, which may have caused fatigue, especially for older adults who required more time for breaks. During data collection of the ratings of perceived difficulty, ratings weren't completely independent. Participants rated the difficulty of the same exercises twice during the first visit, and twice during the second visit. Non-independent ratings may inflate the kappa coefficients in which recalling ratings on the first occasion may have influenced the rating given later (Sim & Wright, 2005). However, due to the large number of exercises included in our study and the fact that the trials were randomized, it would have been difficult for participants to recall previous ratings. Randomizing the testing conditions during the experiment of sessions and visits was attempted to eliminate the order effect due to practice or fatigue.

4.6 CONCLUSION

The results demonstrated that the subjects' performance and their rating of perceived difficulty of standing balance exercises are reliable. The RMS of trunk tilt velocity in the roll direction was the most reliable measure on average. The reliability scores of the sway measures increased after averaging two trials, which indicates clearly the importance of averaging 2 trials.

The ratings of perceived difficulty scales had moderate to strong correlations with quantitative postural measures, demonstrating concurrent validity. Accordingly, either of the two scales (Scale A and B) of ratings of perceived difficulty of balance exercises can be used in clinic to establish a scientific basis for exercise progression.

The strong relationship between the scales and quantitative postural measures in the ML direction suggests that subjects may have based their rating of perceived difficulty on their sway in the medial-lateral direction.

5.0 PERCEPTUAL AND SWAY MEASURES OF BALANCE IN HEALTHY SUBJECTS

5.1 INTRODUCTION

Falling can be a life threatening issue especially for older adults as it might result in death or injuries such as a hip fracture (B. H. Alexander, Rivara, & Wolf, 1992; Cnters for Disease & Prevention, 2016; WHO, 2007). Another adverse consequence for those who have fallen is developing a fear of falling which may result in a reduction in participation in daily life activities and being non-active members in their community (Tinetti et al., 1994).

An association has been found between an increase in postural sway and increased risk of falls. Several studies have reported that an increase in postural sway is a risk factor of falling among older adults (Berg, Maki, Williams, Holliday, & Wood-Dauphinee, 1992; C. J. Chang, Chang, Y. S., & Yang, S. W., 2013). Furthermore, Maki et al. did a prospective study for one year to assess the ability of different clinical and laboratory balance tests to predict risk of future falling. Among the laboratory balance tests, they found that lateral sway optimally distinguished between fallers and non-fallers (Maki et al., 1994).

One of the factors that increases postural sway is getting older (Baloh et al., 1994; Baloh et al., 1998; Gill et al., 2001; Rogind et al., 2003; Sheldon, 1963; Sullivan et al., 2009). Worsening of postural sway in older adults can be a result of poor peripheral sensory systems, vision, (Lichtenstein et al., 1988; Lord et al., 1991b) somatosensation, (Lord et al., 1991b) vestibular function, (Kerber et al., 2006) brain structural changes and related cognitive function reduction, (Baloh et al., 2003; Sullivan et al., 2009; Tell et al., 1998) lower limb muscle weakness and absence of protective reflexes (Aniansson et al., 1986; Larsson et al., 1979).

A number of investigators attempting to prevent falls found that balance training is an important factor in reducing falls in the elderly (Barnett et al., 2003; Howe et al., 2011) as well as improving mobility and functionality for all age groups (Caraffa, Cerulli, Projetti, Aisa, & Rizzo, 1996; Emery, Rose, McAllister, & Meeuwisse, 2007). Customized balance exercises and vestibular rehabilitation therapy (VRT) are considered to be effective options to improve balance by facilitating the central nervous system's ability to compensate for balance deficits (Hillier & McDonnell, 2011; Horak et al., 1992; Shepard & Telian, 1995). These treatments have elicited beneficial results in improving balance in older adults and people with vestibular disorders, eliminating the symptoms of vestibular disorders, and reducing falls (Hillier & McDonnell, 2011; Horak et al., 1992).

Balance and vestibular rehabilitation therapy is comprised of different categories of exercises such as static standing, weight shifting, anticipatory postural adjustments, gait, and eye-head coordination (Alsalaheen et al., 2013; Klatt et al., 2015). Exercises in these categories can be performed in different ways by combining various modifying factors, such as the use of visual feedback, different sizes of the base of support, and head movements (Alsalaheen et al., 2013; Klatt et al., 2015). Some of these exercises and conditions are considered to be more difficult than others, in terms of causing a loss of balance or increasing sway. However, the evidence for determining the appropriate progression of balance exercise intensity is very limited according to the American College of Sports Medicine (ACSM) (Pescatello & American College of Sports Medicine., 2014). In addition, Farlie et al (2013) performed a systematic review of balance intervention studies and found that there was no description of the intensity of balance exercises (Farlie et al., 2013). Typically, a physical therapist will intuitively progress the challenge of balance exercises based on their clinical experience by decreasing proprioception information (e. g. standing on foam), visual information (e. g. closing eyes), or changing the base of support (e. g. standing in semi-tandem stance) (Herdman & Clendaniel, 2014) (Herdman & Clendaniel, 2014).

Several groups have attempted to develop a way to grade the intensity of balance exercises. Muehlbauer et al. assessed the relative difficulty of 12 balance exercises in order to progression sequence. Young subjects stood in 4 different bases of support (feet apart, semi tandem, tandem, and single leg) on either a firm surface with eyes open, foam surface with eyes open, or firm surface with eyes closed. COP displacement was used to assess intensity, and increased gradually from exercises done on a firm surface with eyes open, to foam surface with eyes open, to firm surface with eyes closed. In addition, COP displacement increased as the base of support changed from feet apart, to semi tandem, to tandem and finally to single leg stance. They reported a sequence of 12 exercises, starting from the exercise that produced the least COP displacement to the exercise that produced the most COP displacement (Muehlbauer, Roth, Bopp, & Granacher, 2012). Others have explored the verbal and nonverbal responses during exercises of different levels of difficulty so that they could develop an instrument that measured the intensity of balance difficulty (Farlie et al., 2016). As the difficulty of the exercises increased, the time delay before commencing the exercise increased as well as the number of comments that subjects made before, during, and after exercises increased accordingly with the increased difficulty of the exercise. Additionally, they visually observed the physical responses and found that postural sway and postural reactions such as stepping and reaching increased as the exercise difficulty increased. Furthermore, at the end of each exercise, they asked their subjects to describe their perception of how difficult they found the exercise. The subjects' perception seemed to correlate positively with exercise intensity (Farlie et al., 2016).

For aerobic and resistance exercises, there are very well defined rules for how to determine the initial prescription for exercise intensity as well as how to progress the intensity level. According to the American College of Sports and Medicine (ACSM) guidelines, the initial intensity prescription of aerobic exercise is 40-60% of the heart rate reserve, which is considered a moderate intensity and may be progressed to a vigorous intensity (60-85%) during endurance training and general aerobic exercises (Pescatello & American College of Sports Medicine., 2014). The prescribed intensity may vary depending on the fitness level and goals of the trainee, and whether the trainee has chronic diseases (Pescatello & American College of Sports Medicine., 2014). Similarly, the intensity of resistance training is defined as a percentage of one repetition maximum (1 RM), which is the maximum weight that can be lifted one time throughout the full range of motion. The ACSM recommends different intensity ranges depending on the type of exercise, whether it is muscular strength, endurance, or hypertrophy, and also the intensity depends on the level of the trainee (beginners, intermediate, or advanced). To increase muscular strength, the intensity should be between 60-70% of 1 RM for a novice or intermediate level and between 80-100% for advanced trainees. For muscular endurance, the ACSM recommends that the intensity of the resistance exercises to be lower than 70% of 1 RM, whereas, it is suggested for a novice and intermediate trainee to left weights of an intensity between 70-85% of 1 RM and 70-100% for advanced trainees in order to increase muscle mass (Pescatello & American College of Sports Medicine., 2014).

Furthermore, the rating of perceived exertion for aerobic and resistance exercises was developed to assist in determining how trainees perceive the intensity of activity in cases where the heart rate reserve or the maximum weight that can be lifted cannot be measured, due to medical conditions (e.g. heart failure), using a medication that affects the heart rate in response to physical effort, or lack of medical equipment to measure the event of interest (Robertson et al., 2004; Robertson et al., 2003; Utter et al., 2004). During training programs, rating of perceived exertion scales help to monitor the intensity of the activity and provide healthcare providers with feedback of how hard their clients' feel like they are exercising as well as if their clients are ready to progress to the next level of intensity.

During balance exercises, measuring or visually observing the amount of sway is a common method of assessing the difficulty of exercises. However, many clinics don't have the capability to record sway or interpret its results. In addition, visual observation is an imprecise tool, and evidence of inter-rater reliability has not established. Therefore, the use of rating perceived difficulty scales, which were validated in a different study (Chapter 4), may be beneficial for determining the intensity of balance exercises and may assist with creating the exercises progression.

In this study, we measured the trunk tilt induced during common static standing balance exercises, and asked subjects to rate their perceived difficulty of each exercise in order to establish a standard way of assessing level of difficulty of the exercises (i.e. intensity). Trunk tilt and ratings of perceived difficulty measurements may facilitate better treatment progression algorithms used in practice and research. The purpose of this study was to determine the relative difficulty of a wide variety of static standing exercises commonly performed in balance and vestibular rehabilitation, and validate common rubrics for treatment progression by recording postural sway measures (trunk tilt) and perceived difficulty. In addition, the effect of age on postural and perceptual measures of balance will also be examined.

5.1.1 Specific aim

Specific aim of this study: To examine the perceptual difficulty and postural measures of static standing balance exercises in healthy adults from 18 to 85 y/o.

Hypothesis 1:

During the performance of balance exercises, trunk tilt sway measures and ratings of perceived difficulty will increase (get worse) from the youngest to the oldest age group.

Hypothesis 2:

Trunk tilt sway measures and rating of perceived difficulty will increase as static stance balance exercises change from: level surface to foam surface, eyes open to eyes closed, head still to yaw or pitch movement, and feet apart to semi-tandem stance.

Hypothesis 3:

The increase in magnitude of trunk tilt sway measures will be greater as age increases as static stance balance exercises change from: level surface to foam surface, eyes open to eyes closed, head still to yaw or pitch movement, and feet apart to semi-tandem stance.

5.2 METHODS

5.2.1 Participants

Sixty-two healthy subjects who were independently participating in daily activities, and were between the ages of 18 and 85 years old (31 females and 31 males, mean age 55 ± 20 years) participated in this study. Study participants were distributed into four groups as follow: young (18-44 years old; n = 17), middle aged (45-59 years old; n = 15), old (60-74 years old; n = 15), and very old (75-85 years old; n = 15). Age divisions were developed based on age-related changes in the postural sway found in several studies (Abrahamova & Hlavacka, 2008; Baloh et al., 1998; Era et al., 2006; Gill et al., 2001; Liaw et al., 2009; Rosenhall & Rubin, 1975; Sheldon, 1963).

Subjects were excluded if they were unable to stand for 3 minutes without rest; had distal sensory loss (unable to complete the Romberg test for 30 seconds and unable to feel a pressure of 4.31 g monofilament applied on two different parts of each foot with eyes closed); had visual acuity worse than 20/40; had a diagnosis of benign paroxysmal positional vertigo (BPPV) (positive Dix–Hallpike test or positive Roll test); had neurological or orthopedic disorders; used an assistive device for ambulation; were pregnant; had excessive weight (BMI > 35, had cognitive impairment ≤ 25 points on the Montreal Cognitive Assessment; had a history of falling 2 times or more within the last 12 months doing activities of daily living; or had a peripheral vestibular disorder (positive head thrust test)).

This study was approved by the Institutional Review Board at the University of Pittsburgh. All subjects signed the written research consent form prior to participating in the study.

5.2.2 Instrumentation

During the performance of the exercises in static standing, subjects stood on a force platform (NeuroTest, NeuroCom, Inc., Clackamas, OR) that measured ground reaction forces at a sampling rate of 100 Hz. An inertial measurement unit (IMU, Xsense Technologies B.V., Enschede, The Netherlands) was mounted on each subject's lower back at the level of the iliac crest (L4) to measure trunk angular displacement and velocity from vertical, and linear acceleration in AP and ML directions at a sampling rate of 100 Hz. The IMU uses a combination of accelerometers, gyroscopes, and a magnetometer.

5.2.3 Experimental procedure

The study is an experimental study using a within-subjects and between-groups design to determine the effect of age and different exercise conditions on balance. All potential research participants had a screening visit. The eligible subjects were asked to come back for 2 test visits, one week apart. The independent variables are the age groups (4 levels) and the exercise conditions (i.e. surface - 2 levels; visual input - 2 levels; base of support - 2 levels; and head movement - 3 levels). The different levels of exercise conditions are shown in Table 5-1.

Table 5-1: Chosen conditions of static standing exercises

Exercise category	Surface	Visual input	Base of support	Head movement
Static standing	Level surface Foam surface	Eyes open Eyes closed	Feet apart Semi-tandem	Head still Yaw Pitch

5.2.3.1 Screening visit

Consented subjects underwent screening tests to rule out conditions known to adversely affect balance. Screening tests included: Romberg stance (Horak, 1987), lower extremity pressure threshold using monofilaments (Holewski et al., 1988), visual acuity (Brien Holden, 2008; Muhammad et al., 2015; World-Health-Organization, 2003), the Montreal Cognitive Assessment - Version 3 (Nasreddine et al., 2005), the Dix–Hallpike Test (Dix & Hallpike, 1952), the supine roll test (Lempert & Tiel-Wilck, 1996), and the Head Impulse Test (Halmagyi & Curthoys, 1988).

Eligible subjects who met the study criteria completed the Activities-specific Balance Confidence Scale (ABC) questionnaire (Powell & Myers, 1995), the Functional Gait Assessment (FGA) (Wrisley et al., 2004), and gait speed (Steffen et al., 2002) was measured prior to the experiment in order to better describe the participants. More detail description of the screening tests is in Chapter 3.

5.2.3.2 Experimental visits

Participants were tested during two experimental visits, one week apart. During each experimental visit, participants performed two sets of 24 randomized static standing balance exercises, which were a full-factorial design of the following different conditions: vision (eyes open and eyes closed); surface (firm and foam); base of support (feet apart and semi-tandem); and head movements (head still, yaw, and pitch) as shown in Table 5-2.

Table 5-2: Static standing balance exercises

Exercise number	Surface conditions	Visual input	Base of support	Head movement
1	Firm	Eyes open	Feet apart	Head still
2	Firm	Eyes open	Feet apart	Yaw
3	Firm	Eyes open	Feet apart	Pitch
4	Firm	Eyes open	Semi-tandem	Head still
5	Firm	Eyes open	Semi-tandem	Yaw
6	Firm	Eyes open	Semi-tandem	Pitch
7	Firm	Eyes closed	Feet apart	Head still
8	Firm	Eyes closed	Feet apart	Yaw
9	Firm	Eyes closed	Feet apart	Pitch
10	Firm	Eyes closed	Semi-tandem	Head still
11	Firm	Eyes closed	Semi-tandem	Yaw
12	Firm	Eyes closed	Semi-tandem	Pitch
13	Foam	Eyes open	Feet apart	Head still
14	Foam	Eyes open	Feet apart	Yaw
15	Foam	Eyes open	Feet apart	Pitch
16	Foam	Eyes open	Semi-tandem	Head still
17	Foam	Eyes open	Semi-tandem	Yaw
18	Foam	Eyes open	Semi-tandem	Pitch
19	Foam	Eyes closed	Feet apart	Head still
20	Foam	Eyes closed	Feet apart	Yaw
21	Foam	Eyes closed	Feet apart	Pitch
22	Foam	Eyes closed	Semi-tandem	Head still
23	Foam	Eyes closed	Semi-tandem	Yaw
24	Foam	Eyes closed	Semi-tandem	Pitch

Participants stood without shoes in order to avoid the confounding effect of wearing different shoes. During conditions of foam surface, subjects stood on a foam pad (AIREX Balance Pad S34-55) that had a height of 6 cm, length of 51 cm, width of 40 cm (density 55 kg/m^3, compression resistance 20 kPa at 25% compression) and the room's temperature was maintained at a median value of 72 Fahrenheit degrees with an interquartile range of 3 degrees during all visits to avoid the change of foam properties (see Appendix C). During the different base of support stances, subjects were asked to distribute their body weight equally on each foot, and to stand during the feet apart condition with the heel centers 0.17 m apart, with an angle of

14 degrees between the long axes of the feet (McIlroy & Maki, 1997). For the semi-tandem stance conditions, subjects stood with the front foot touching the medial side of the other foot by a half of foot length (Lee et al., 2012; Nejc et al., 2010), with the dominant foot in the back. During the eyes closed conditions, subjects wore opaque goggles. During yaw and pitch conditions, subjects were instructed to move their head at a frequency of 1 Hz by following the beat of a metronome (Hall & Herdman, 2006) within a range of 45 degrees in the yaw direction (Jung et al., 2009) and 30 degrees in pitch direction. Subjects practiced the head movement in these directions with a laser light attached to the head before they started the experiment. However, the laser light wasn't used during the experiment.

Exercises were performed in random order that was software-generated. Subjects were instructed to stand as steady as possible with their arms at their side (Gill-Body et al., 1994; Gill et al., 2001) during all trials for 35 seconds each (Allum et al., 2011; Le Clair & Riach, 1996; Muehlbauer et al., 2012; Rine et al., 2013). Data collection was stopped if a subject lost balance according to the following failure criteria: stepped out of position, changed their feet or arms starting position, and/or touched something for support. Subjects were asked to repeat failed trials only once in each set if they lost their balance before completing 25 seconds of the 35s trials. Subjects were guarded by a physical therapist during all exercises to prevent falling and wore a safety harness which was attached to an anchor point in the ceiling that does not let subject reach the ground in case of a fall incidence. There was a seated rest break for 1 minute after every 3 exercises to avoid fatigue.

In addition, subjects rated the perceived difficulty of each exercise they performed using two different scales. The first scale was a modified rating of perceived difficulty scale based on rating of perceived exertion scales for aerobic and resistance exercises (Scale A) (Robertson et al., 2004; Robertson et al., 2003) that ranges from 0 to 10, where 0 indicates that the exercise is extremely easy whereas 10 indicates that the exercise is extremely hard (Figure 5-1). The second scale was developed for this study and was anchored with colors and statements (Scale B) (Espy et al., 2015) (Figure 5-2). Scale B had 5 levels ranging from A to E, where A was anchored with the following statement; “I feel completely steady” and E was labeled as “I lost my balance”. In the statistical analysis, letters from scale B were transformed to numbers as follows; A = 1, B = 2, C = 3, D = 4, and E = 5.

Before starting the experiment, both scales were presented and explained to subjects that they needed to choose, after each exercise, a number from the 1st scale and a letter from the 2nd scale that indicated the difficulty of maintaining their balance during that exercise. During the experiment, the scales were placed on the side wall so that subjects could look at them after each exercise whenever needed.

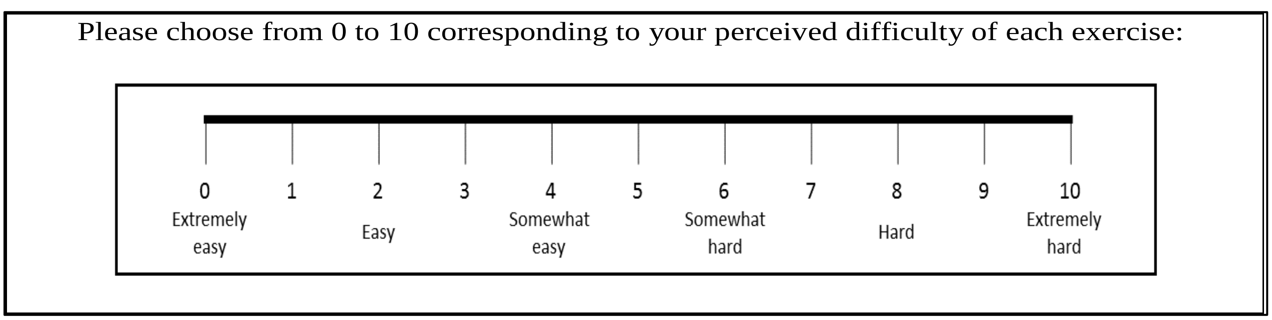


Figure 5-1: Scale A; Rating of perceived difficulty scale, based on OMNI rating of perceived exertion scale (Robertson et al., 2004; Robertson et al., 2003)

Please choose from A to E corresponding to your perceived difficulty of each exercise:	
I feel completely steady	**A**
I feel a little unsteady or off-balance	**B**
I feel somewhat unsteady or like I may lose my balance	**C**
I feel very unsteady or like I definitely will lose my balance	**D**
I lost my balance	**E**

Figure 5-2: Scale B; Rating of perceived difficulty scale, adapted from a poster from Cleveland State University (Espy et al., 2015)

5.2.4 Outcome measures

Demographic data:

Demographic data including age, gender, weight, and height were summarized by descriptive statistics. Additionally, the average scores of the Functional Gait Assessment, Activities-specific Balance Confidence Scale (ABC) questionnaire, and gait speed for all groups were recorded.

Sway measures:

Sway measures were recorded during all trials for 35 seconds with the first five seconds of data collection removed in order to avoid the effect of the subject's initial establishment of balance (O'Sullivan et al., 2009; Rine et al., 2013). Summary measures of trunk sway were calculated from the 30 seconds time series. The data was low-pass filtered using a second order Butterworth filter with a cut-off frequency of 3 Hz (Dozza et al., 2005; Dozza, Horak, et al., 2007). During the analysis, each trial was plotted individually and inspected visually using MATLAB software to assure that there were no extraneous movements.

The Root Mean Square (RMS) of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions were calculated and used in the analysis to test the hypotheses. The RMS was calculated as follows:

$$\text{RMS} = \sqrt[2]{\frac{\sum_{i=0}^{n}\left(a_i^2\right)}{n}}$$

where a is instantaneous sway value with mean value subtracted, and n is an individual data sample, and N is the total number of samples. The mean value was subtracted before calculating the RMS.

Additionally, the 90% range of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions as well as the interquartile range (75th percentile – 25th percentile) of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions were calculated. The 90% range of angular displacement is the difference between the 95th percentile value and the 5th percentile value. The interquartile range is the difference between the upper quartile (the 75th percentile value) and the lower quartile (the 25th percentile value). The previous two measures were collected to set ranges of normal limits of sway for different age groups so they can be used as a reference normative data when comparing patients' data. Additionally, these values could be used for augmented sensory feedback devices to set the threshold when feedback can be provided.

Due to technical problems with the force platform that we encountered during data collection causing a loss of high percentage of data (27% in middle-aged group's data, 20% in old group's data, and 13% in very old group's data), the COP data were excluded from the final analysis to test the hypotheses.

5.2.5 Statistical Analyses

Participants' demographic characteristics were compared between groups using one-way ANOVA test for dependent variables that were continuous and normally distributed and post hoc comparisons were conducted to evaluate pairwise differences among the groups with the Sidak approach used to control for Type 1 error (Sidak, 1967). The Kruskal-Wallis test was used with dependent variables that were continuous but not normally distributed and Dunn's procedure (Olive Jean Dunn, 1964) was used for pairwise comparisons with a Bonferroni correction for multiple comparisons.

Postural Sway:

A Linear Mixed Model (LMM) was used to test the three hypotheses of the study. A linear mixed model was used to explore the main effects of five independent variables; age group and the four exercise conditions (types of stance, visual input, surface, and head movements) as well as to explore two-way interaction effects between age groups and surface types, visual inputs, stance types, and head movements on quantitative postural measures (RMS of trunk angular displacement and velocity in the pitch and roll directions, and trunk linear acceleration in the AP and ML acceleration). The linear mixed model contains fixed effects and random effects. In this study, fixed effects are age group, surface type, visual input, stance condition, and head movement, whereas the random effect is the subject. Due to the presence of missing data in this study, the decision was made to use a LMM as it allows us to evaluate the effects with the presence of having missing data. Additionally, a LMM allows inclusion of a random effect, subjects, and assumes that each subject has his/her own intercept value.

The autoregressive order 1 (AR1) covariance structure was used, which assumes homogeneous variance and unequal covariance between observations on the same subject

(Littell, Pendergast, & Natarajan, 2000). Several different covariance structures were evaluated and the AR1 had the best model fit and best reflected the unadjusted means.

The average value of all 4 trials of the dependent variables (2 trials per visit and 2 visits) were used because it was determined that there was no difference between trials or visits. A Sidak correction for multiple comparisons was used for post-hoc analysis of significant main effects related to age and head movement. Normality was tested using the Shapiro–Wilk test. The significance level was $\alpha = 0.05$.

Rating of Perceived Difficulty:

For rating of perceived difficulty data, which was ordinal, the Kruskal-Wallis test was used for comparison of more than two independent samples (age groups) and Dunn's procedure was used for pairwise comparisons with a Bonferroni correction for multiple comparisons. The Friedman test was used for comparison of more than two dependent samples (head movement conditions) followed by Wilcoxon signed-rank tests for pairwise comparisons with a Bonferroni correction for multiple comparisons (O. J. Dunn, 1961). The Wilcoxon signed-rank test was used for comparison of two dependent samples (surface conditions, visual inputs, stance conditions). The mean value of all 4 trials (2 trials per visit and 2 visits) of the rating of perceived difficulty from Scales A & B was used.

Static Standing Balance Exercises Sequence:

A hierarchical cluster analysis (HCA) was used to categorize the exercises into five clusters (very easy, easy, moderate, hard, and very hard) to help physical therapists to establish a scientific basis for exercise progression. The HCA was conducted using the pitch and roll tilt velocity measures because they were determined to have the greatest reliability, and both ratings of perceived difficulty scales.

5.3 RESULTS

5.3.1 Descriptive statistics:

Of 72 people who underwent onsite screening, 62 participants completed the study and were assigned into four groups as shown in Table 5-3. The 10 subjects who dropped out had a mean age of 64 ± 14 years. Eight subjects were excluded because they did not pass the inclusion criteria (4 did not pass the cognitive test; 3 did not pass the monofilament test; 1 did not pass the roll test), 1 subject was excluded due to a behavioral issue, and 1 subject did not come back for follow up visits. The eligible 62 participants had a mean age of 55 ± 20 years. The mean values of gait speed for all age groups were within the normal range (Abellan et al., 2009; Hornyak et al., 2012; Lusardi et al., 2003), and within higher levels of physical functioning based on their scores on the Functional Gait Assessment (FGA) (Walker et al., 2007; Wrisley & Kumar, 2010) and the Activities-specific Balance Confidence (ABC) Scale (Huang & Wang, 2009; Myers et al., 1998; Powell & Myers, 1995).

Table 5-3: Participants' Demographic Characteristics

	All participants (18-85)	Young (18-44)	Middle aged (45-59)	Old (60-74)	Very old (75-85)
	Total (n=62)	Total (n=17)	Total (n=15)	Total (n=15)	Total (n=15)
Age, y, M ± SD	55 ± 20	28 ± 8	53 ± 4	67 ± 4	79 ± 3
Gender, female, n (%)	31 (50)	9 (53)	8 (53)	7 (47)	7 (47)
Body Mass Index, kg/m^2, Median (Range)	26.3 (15.5-35.8)	21.8 (18.1-33.5)	27.5 (18.1-32.1)	29.9 (15.5-34.8)	27.8 (19.9-35.8)
Monofilament, Median (Range)	4.08 (2.83-4.31)	3.84 (2.83-4.08)	4.08 (2.83-4.31)	4.08 (3.61-4.17)	4.17 (3.61-4.31)
Montreal Cognitive Assessment, Median (Range)	29 (26-30)	29 (26-30)	28 (26-30)	29 (26-30)	28 (26-30)
The Activities-specific Balance Confidence (ABC) Scale, Median (Range)	97 (81-100)	99 (89-100)	94 (83-100)	98 (81-100)	91 (88-99)
Gait Speed, m/s, M ± SD	1.30 ± 0.20	1.38 ± 0.20	1.39 ± 0.21	1.26 ± 0.19	1.16 ± 0.12
Functional Gait Assessment, Median (Range)	28 (19-30)	29 (27-30)	29 (23-30)	28 (19-30)	24 (19-29)

A One-Way ANOVA was conducted to test the differences between the four age groups (Young, Middle aged, Old, Very old) on gait speed. There was a significant difference between groups on gait speed [F (3, 58) = 5.26, p = 0.003]. Post hoc comparisons indicated that the mean score of the young group (M = 1.38, SD = 0.2 m/s) and the middle-aged group (M = 1.39, SD = 0.21 m/s) were significantly different from the very old group (M = 1.16, SD = 0.12 m/s).

A Kruskal-Wallis test was conducted to evaluate differences among the four age groups (Young, Middle aged, Old, and Very old) on the Body Mass Index (BMI), Activities-specific Balance Confidence Scale (ABC) questionnaire, Functional Gait Assessment (FGA) and there was a significant difference between some of the groups on all these variables. The pairwise comparisons showed significant differences between the young group and the old group and the very old group on BMI, the young group and the very old group on the ABC, and between the very old group and all the other groups (young, middle-aged, and old) on the FGA.

Reviewing the rate of successfully completed exercises in each age group revealed that most subjects in the young group were able to complete all exercises with the exception of No. 23 (foam surface, eyes closed, semi-tandem stance, and yaw head movement) with an incompletion rate of 14.7% (Table 5-4). The majority of the middle-aged group could complete all exercises except No. 23, and No. 24 (foam surface, eyes closed, semi-tandem stance, and pitch head movement) with incompletion rates of 66.7%, and 65% respectively. Subjects in the old group had more difficulty completing more exercises [17 (foam surface, eyes open, semi-tandem stance, and yaw head movement), 18, 23, and 24] with higher incompletion rates (13.3 – 73.3%). The number of exercises that subjects aged 75 through 85 years could not perform increased compared with other groups: [11 (firm surface, eyes closed, semi-tandem stance, and yaw head movement), 12 (firm surface, eyes closed, semi-tandem stance, and pitch head movement), 17, 18, 21 (foam surface, eyes closed, feet apart stance, and pitch head movement), 22 (foam surface, eyes closed, semi-tandem stance, and head still), 23, and 24] with incompletion rate ranges between 11.7% - 96.7% (see Table 5-4). Due to the high incompletion rate of exercises 23 and 24, they were eliminated from the linear mixed model analysis.

Table 5-4: Incompletion rates of balance and vestibular exercises

Exercise number	Incompletion rate (%)			
	Group 1	Group 2	Group 3	Group 4
1				
2				
3				
4				1.7
5				3.3
6			1.7	
7				
8		1.7		
9				
10				5.0
11		5.0	6.7	31.7
12				20.0
13				1.7
14				
15				6.7
16				1.7
17		6.7	13.3	46.7
18		10.0	21.7	51.7
19				
20			5.0	8.3
21			3.3	11.7
22		3.3	6.7	35.0
23	14.7	66.7	73.3	96.7
24	7.4	65.0	63.3	85.0

5.3.2 Postural Sway

The normality of postural sway measures scores was assessed by the Shapiro-Wilk's test ($p > .05$) and the assumption of normality was not rejected. Despite the presence of some outliers, as assessed by inspection of the boxplot, the outliers were examined individually and kept in the analysis because they seemed to represent actual values of human sway. The mean (SD) of the dependent variables for each of the fixed effects appears in Table 5-5.

All main effects of age groups, surface conditions, visual inputs, stance conditions, and head movements were statistically significant at the 0.05 significance level on all quantitative postural measures (see Table 5-6).

Table 5-5: Mean (SD) scores of the dependent variables in each level of the independent variables

Variables	Level	RMS of pitch displacement (degree)		RMS of roll displacement (degree)		RMS of pitch velocity (deg/sec)		RMS of roll velocity (deg/sec)		RMS of AP acceleration (m/sec^2)		RMS of ML acceleration (m/sec^2)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age groups	1	0.62	0.24	0.36	0.21	1.41	1.02	0.80	0.54	0.12	0.05	0.08	0.04
	2	0.63	0.29	0.38	0.30	1.44	1.01	0.85	0.70	0.12	0.06	0.09	0.06
	3	0.72	0.39	0.41	0.32	1.58	1.19	0.95	0.78	0.14	0.07	0.10	0.07
	4	0.87	0.49	0.48	0.34	1.76	1.11	1.07	0.83	0.17	0.08	0.12	0.07
Surface	Firm	0.56	0.24	0.31	0.21	1.35	1.02	0.71	0.55	0.11	0.05	0.08	0.05
	Foam	0.89	0.42	0.52	0.34	1.78	1.13	1.15	0.83	0.17	0.08	0.12	0.07
Vision	EO	0.68	0.34	0.43	0.32	1.48	1.03	0.95	0.77	0.13	0.06	0.10	0.07
	EC	0.84	0.41	0.48	0.27	1.85	1.15	1.10	0.66	0.17	0.08	0.12	0.06
Stance	FA	0.66	0.35	0.25	0.14	1.43	1.09	0.63	0.48	0.13	0.07	0.06	0.04
	ST	0.77	0.40	0.60	0.32	1.68	1.08	1.26	0.82	0.15	0.07	0.14	0.07
Head	HS	0.60	0.34	0.37	0.28	0.88	0.62	0.62	0.59	0.11	0.06	0.08	0.06
	Yaw	0.70	0.37	0.44	0.32	1.31	0.68	1.28	0.79	0.13	0.07	0.12	0.07
	Pitch	0.83	0.37	0.41	0.30	2.55	1.12	0.88	0.62	0.17	0.07	0.09	0.06

EO: eyes open; EC: eyes closed; FA: feet apart; ST: semi-tandem; HS: head still.

Table 5-6: Main effects of age group and exercise conditions

	RMS of pitch displacement		RMS of roll displacement		RMS of pitch velocity		RMS of roll velocity		RMS of AP acceleration		RMS of ML acceleration	
Source	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Age group	9.96	< 0.01	7.46	< 0.01	3.64	0.02	5.36	< 0.01	13.15	< 0.01	19.35	< 0.01
Surface	619.90	< 0.01	529.44	< 0.01	386.15	< 0.01	458.41	< 0.01	780.22	< 0.01	750.12	< 0.01
Vision	111.36	< 0.01	16.85	< 0.01	134.17	< 0.01	33.33	< 0.01	192.46	< 0.01	66.51	< 0.01
Stance	208.74	< 0.01	1912.35	< 0.01	196.95	< 0.01	996.81	< 0.01	229.78	< 0.01	2365.86	< 0.01
Head	238.86	< 0.01	134.44	< 0.01	979.43	< 0.01	464.32	< 0.01	510.75	< 0.01	531.38	< 0.01

The main effect of age was statistically significant on all quantitative postural measures (Figure 5-3). Post hoc analyses using the Sidak post hoc criterion for significance indicated that the very old group had higher sway than the young group on all quantitative postural measures; the very old group had higher sway than the middle-aged group on five quantitative postural measures (RMS of trunk angular displacement in the pitch and roll directions, velocity in roll direction, and trunk linear acceleration in the AP and ML acceleration); the very old group had higher sway than the old group on RMS of trunk linear ML acceleration; and the old group had higher sway than the young group on RMS of trunk linear ML acceleration (see Figure 5-3).

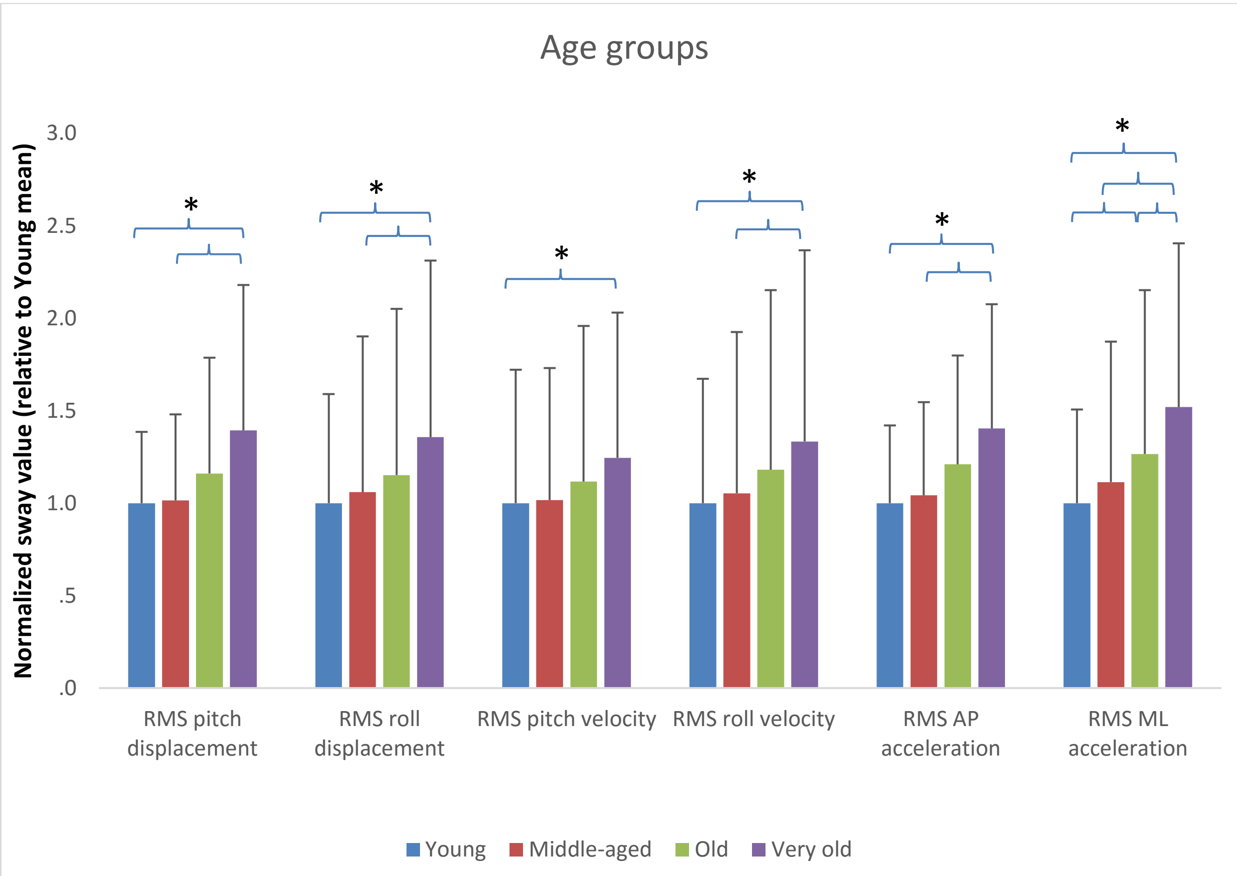


Figure 5-3: Mean scores of RMS trunk displacement, velocity, acceleration in pitch and roll directions in young, middle-aged, old, and very old groups. Error bars represent population standard deviation. * p < 0.05 difference between pairs.

The main effect of surface conditions on all quantitative postural measures was statistically significant such that standing on foam had higher sway than standing on firm surface

(Figure 5-4). The main effect of visual inputs on all quantitative postural measures was statistically significant where standing with eyes closed produced higher sway than standing with eyes open (Figure 5-5). The main effect of stance conditions on all quantitative postural measures was statistically significant indicating that standing in semi-tandem stance generated greater sway than standing with feet apart (Figure 5-6).

The main effect of head movements on all quantitative postural measures was statistically significant. Post hoc analyses using the Sidak approach for significance indicated that all quantitative postural measures were significantly lower during head still condition compared to yaw and pitch conditions; the yaw head movement was significantly greater than pitch movement on all sway measures in the ML direction, and the pitch head movement was significantly greater than yaw movement on all sway measures in the AP direction (Figure 5-7).

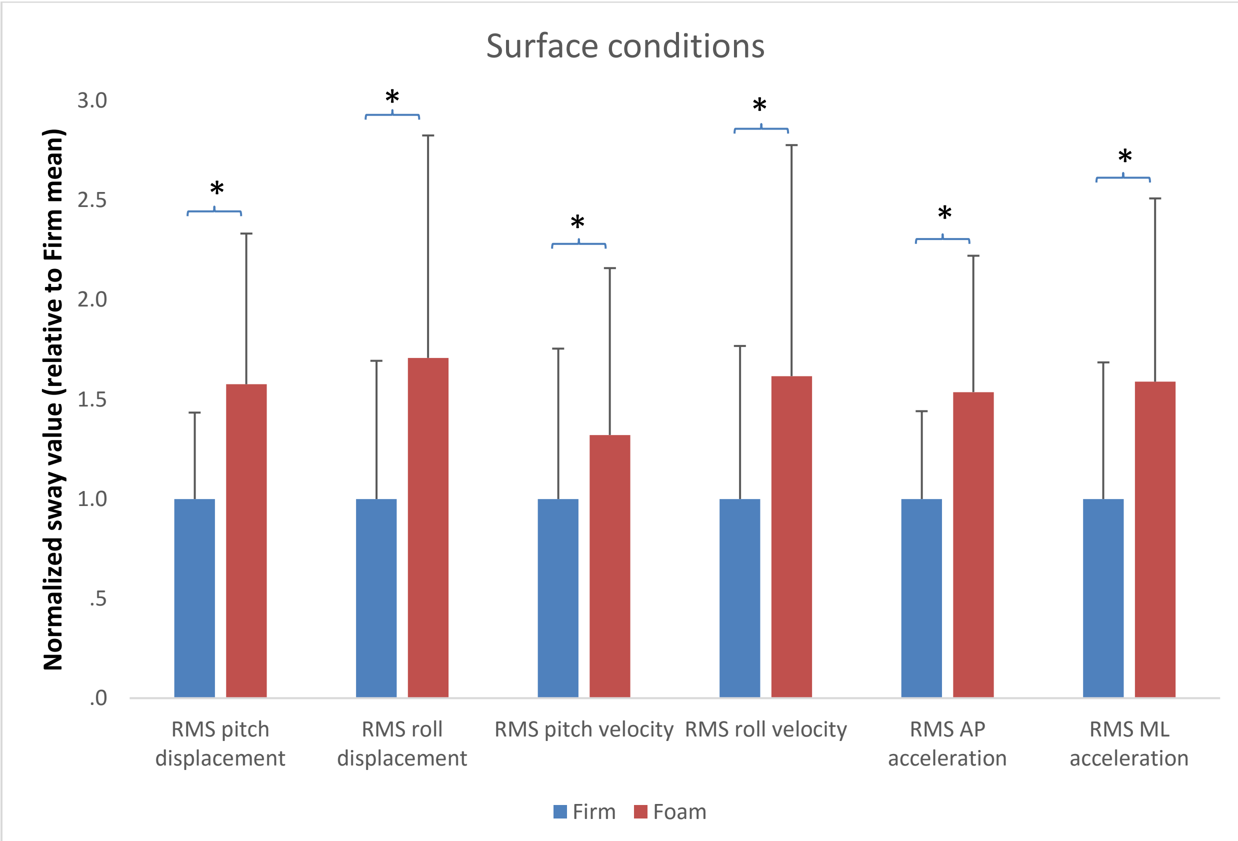


Figure 5-4: Mean scores of RMS trunk displacement, velocity, acceleration in pitch and roll directions during firm and foam conditions. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

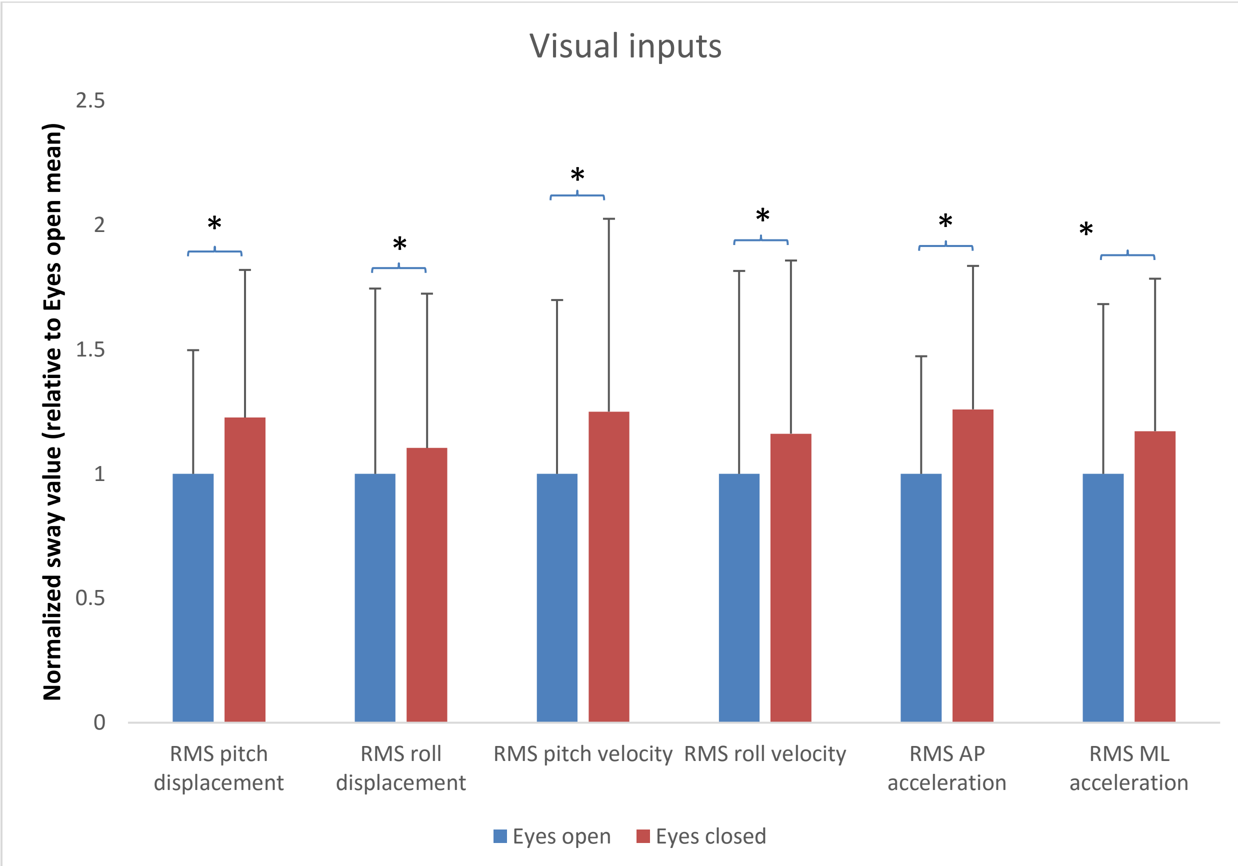


Figure 5-5: Mean scores of RMS trunk displacement, velocity, acceleration in pitch and roll directions during eyes open and eyes closed conditions. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

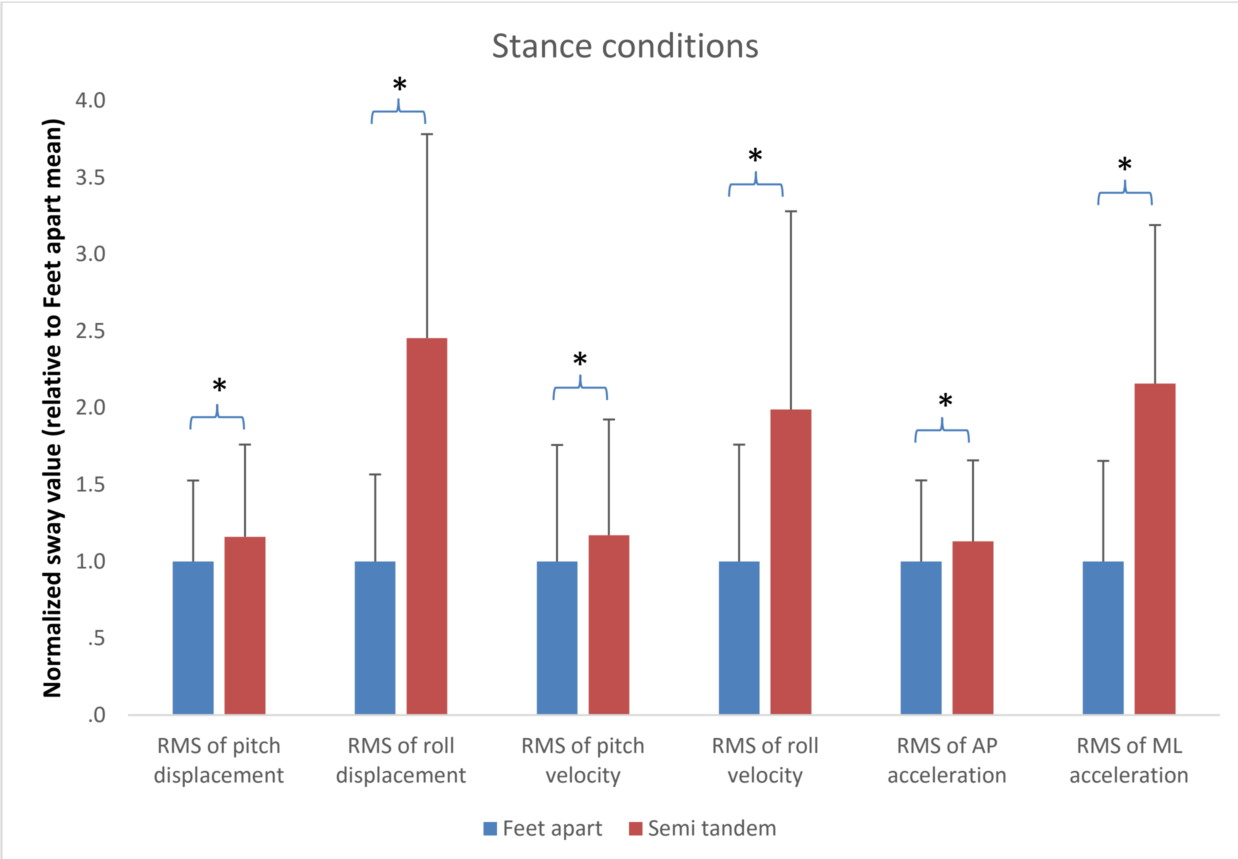


Figure 5-6: Mean scores of RMS trunk displacement, velocity, acceleration in pitch and roll directions during feet apart and semi tandem stance conditions. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

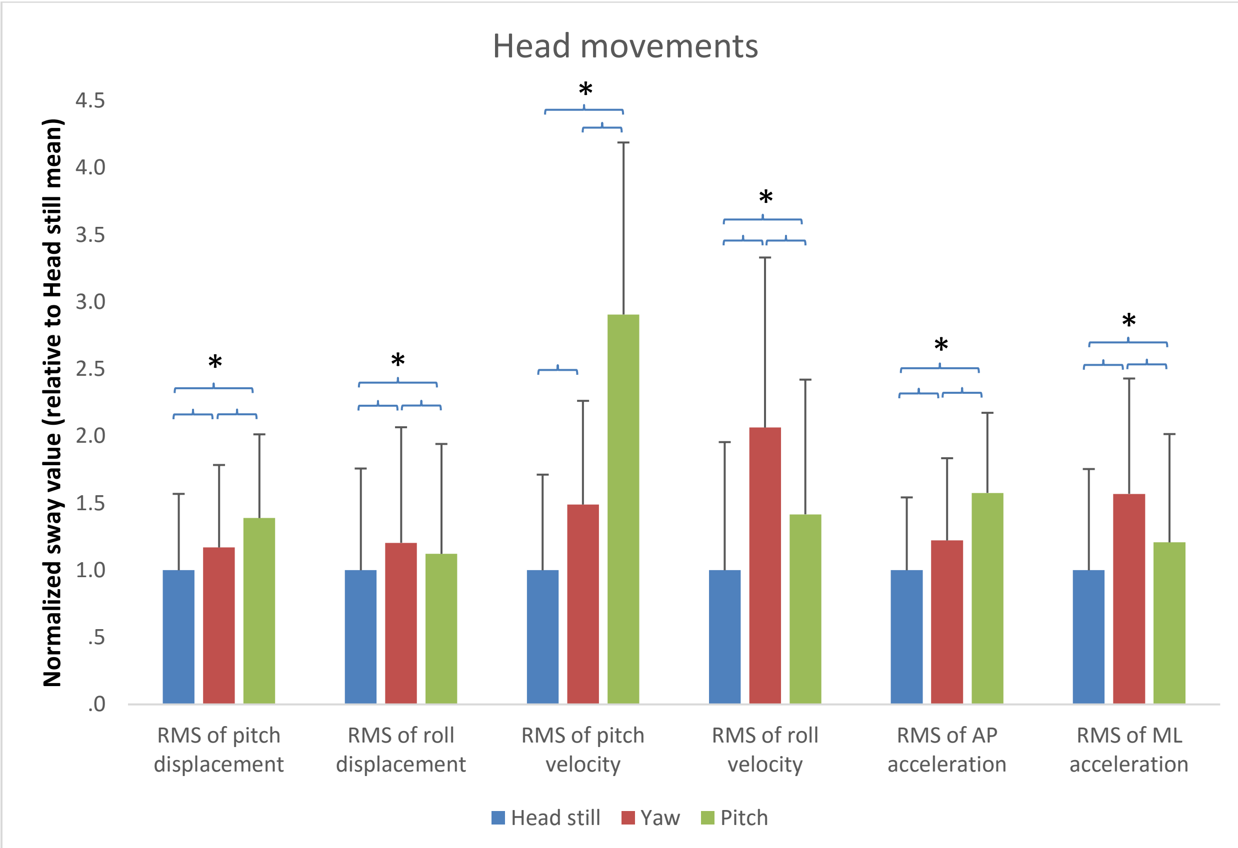


Figure 5-7: Mean scores of RMS trunk displacement, velocity, acceleration in pitch and roll directions during head still, yaw, and pitch movements. Error bars represent population standard deviation. * p < 0.05 difference between pairs.

The linear mixed model was used to explore two-way interaction effects between age group and exercise conditions (surfaces, visual inputs, stances, and head movements) on quantitative postural measures (RMS of trunk angular displacement and velocity in the pitch and roll directions, and trunk linear acceleration in the AP and ML acceleration). There was a significant interaction between age group and surface type, stance type, and head movement in all the sway measures. Conversely, there was no significant interaction between age groups and visual input in all sway measures (see Table 5-7)

Table 5-7: Interaction effects between age groups and exercise conditions in sway measures

	RMS of pitch displacement		RMS of roll displacement		RMS of pitch velocity		RMS of roll velocity		RMS of AP acceleration		RMS of ML acceleration	
Source	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Group * Surface	20.26	< 0.01	8.35	< 0.01	15.74	< 0.01	5.65	< 0.01	20.52	< 0.01	10.99	< 0.01
Group * Vision	2.57	0.05	0.83	0.48	2.16	0.09	0.54	0.65	2.11	0.10	1.32	0.27
Group * Stance	15.66	< 0.01	13.80	< 0.01	15.05	< 0.01	18.62	< 0.01	10.07	< 0.01	18.17	< 0.01
Group * Head	4.77	< 0.01	2.32	0.03	6.33	< 0.01	2.93	0.01	6.39	< 0.01	12.29	< 0.01

There was a significant interaction between age group and surface type in all sway parameters. The RMS pitch velocity will be used to illustrate these interactions. There was not a significant difference between groups while standing on the firm surface. While on the foam surface, sway increased significantly in all groups ($p < 0.05$), and increased by a larger amount as age increased, such that the very old group differed from the young and middle-age groups (Figure 5-8). Similarly, there was not a difference between groups standing with feet apart, but semi-tandem stance increased RMS pitch velocity in all groups ($p < 0.05$), and to a greater extent in the older groups, resulting in significant difference between the very old and the young and middle-age groups (Figure 5-9). In the same way, moving the head in the yaw or pitch direction increased sway among age groups, compared to keeping head still. The amount of the increase varied between the groups. The pitch velocity showed significant differences between young and very old during exercises with head still, and between the very old and all other groups during exercises with yaw head movement. However, during exercises with pitch movement, no significant differences between age groups were found (Figure 5-10).

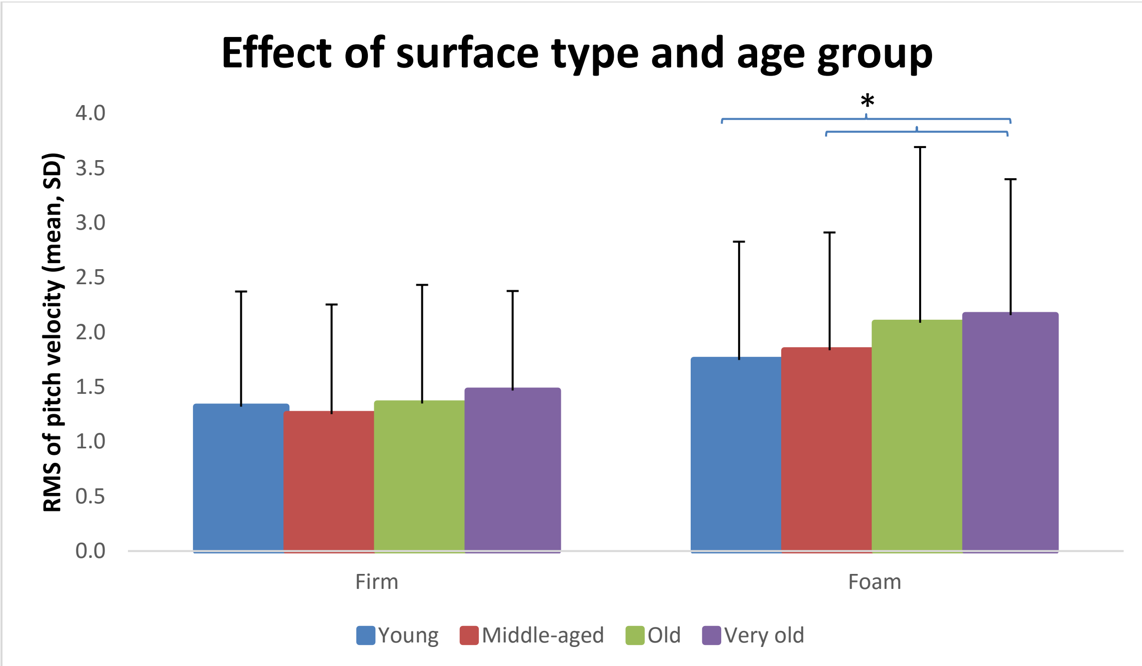


Figure 5-8: Interaction effect between surface type and age group in the RMS of pitch velocity (mean, SD). * p < 0.05 difference between pairs.

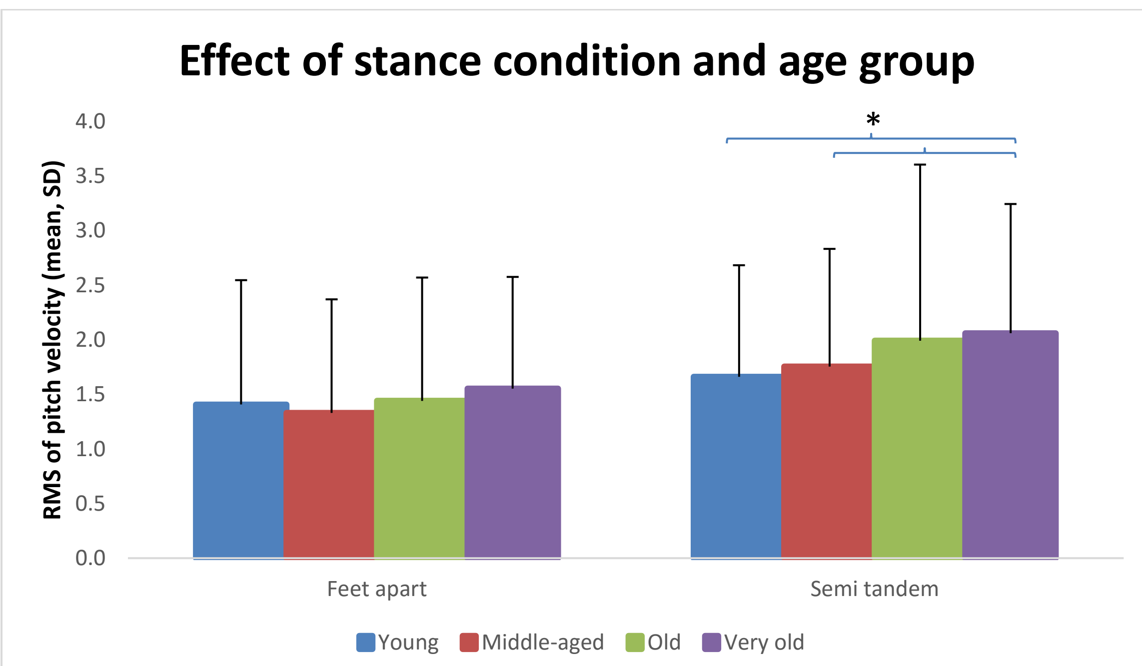


Figure 5-9: Interaction effect between stance condition and age group in the RMS of pitch velocity (mean, SD). * p < 0.05 difference between pairs.

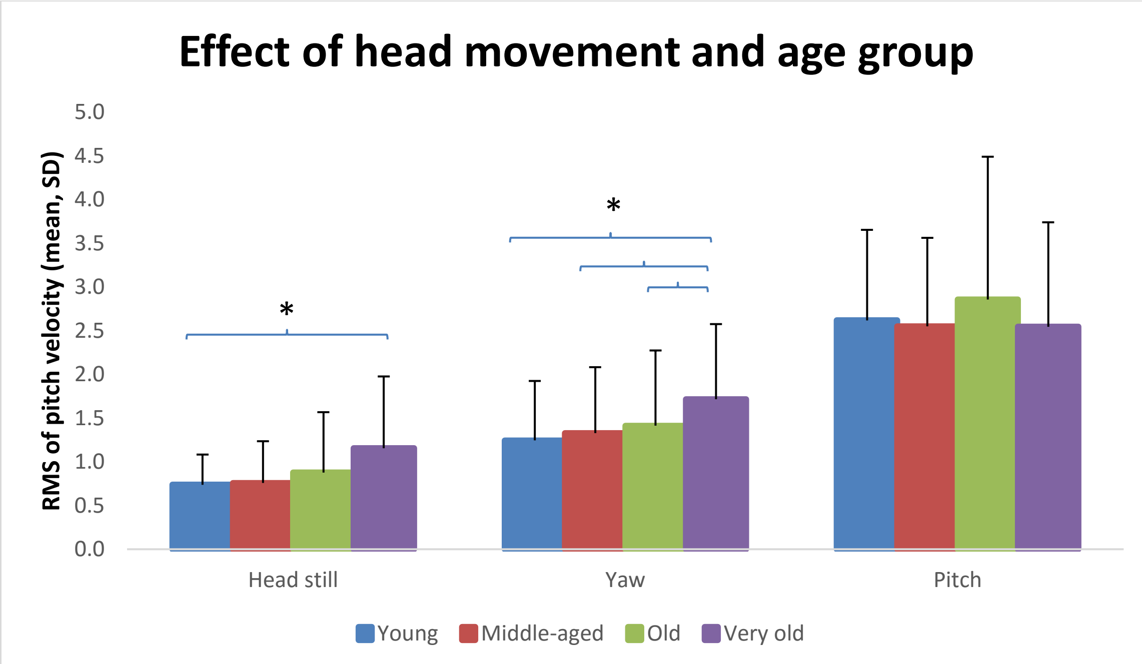


Figure 5-10: Interaction effect between head movements and age group in the RMS of pitch velocity (mean, SD). * p < 0.05 difference between pairs.

5.3.3 Rating of perceived difficulty

The mean scores of the ratings of perceived difficulty scales A and B are displayed in Table 5-8. A Kruskal-Wallis test demonstrated significant differences between the age groups on Scale A (H=27.31, p < 0.001) and Scale B (H=34.31, p < 0.001). The pairwise comparisons showed significant differences on Scales A and B between the young group and old group, the young group and very old group, and middle-aged group and very old group (see Figure 5-11).

A Wilcoxon signed-rank test determined that there was a significant difference between the type of surface (Z=6.85, p <0.001) (Z=6.85, p <0.001), type of visual input (Z=6.85, p <0.001) (Z=6.85, p <0.001), and type of stance (Z=6.85, p <0.001) (Z=6.85, p <0.001) on the rating of perceived difficulty Scales A and B respectively, with increased ratings on foam compared with firm, eyes closed versus eyes open, and semi-tandem stance related to feet apart (see Figures 5-12, 5-13, 5-14).

The Friedman test was used for comparison among the three head movements (head still, yaw, pitch) on the rating of perceived difficulty Scales A and B, and revealed that mean scores of Scales A and B were significantly different between the different types of head movement ($H=93.34$, $p < 0.001$) ($H=93.98$, $p < 0.001$) respectively. The post hoc analysis revealed statistically significant differences on Scales A and B between the head still and yaw head movements, and head still and pitch head movements, but not between the yaw and pitch head movements (see Figure 5-15).

Table 5-8: Mean scores of the dependent variables (Scales A and B) in each level of the independent variables

Independent variables	Level	Scale A (0-10)		Scale B (1-5)	
		Mean	SD	Mean	SD
Age group	Young	2.43	0.86	1.61	0.26
	Middle-aged	3.31	1.05	2.02	0.32
	Old	3.80	0.97	2.25	0.31
	Very old	4.98	1.25	2.63	0.51
Surface	Firm	2.32	1.32	1.58	0.46
	Foam	4.87	1.54	2.64	0.62
Vision	Eyes open	2.96	1.35	1.84	0.50
	Eyes closed	4.22	1.45	2.37	0.56
Stance	Feet apart	2.05	1.20	1.48	0.39
	Semi-tandem	5.13	1.73	2.74	0.69
Head	Head still	2.68	1.34	1.75	0.46
	Yaw	4.07	1.45	2.31	0.55
	Pitch	4.02	1.45	2.27	0.58

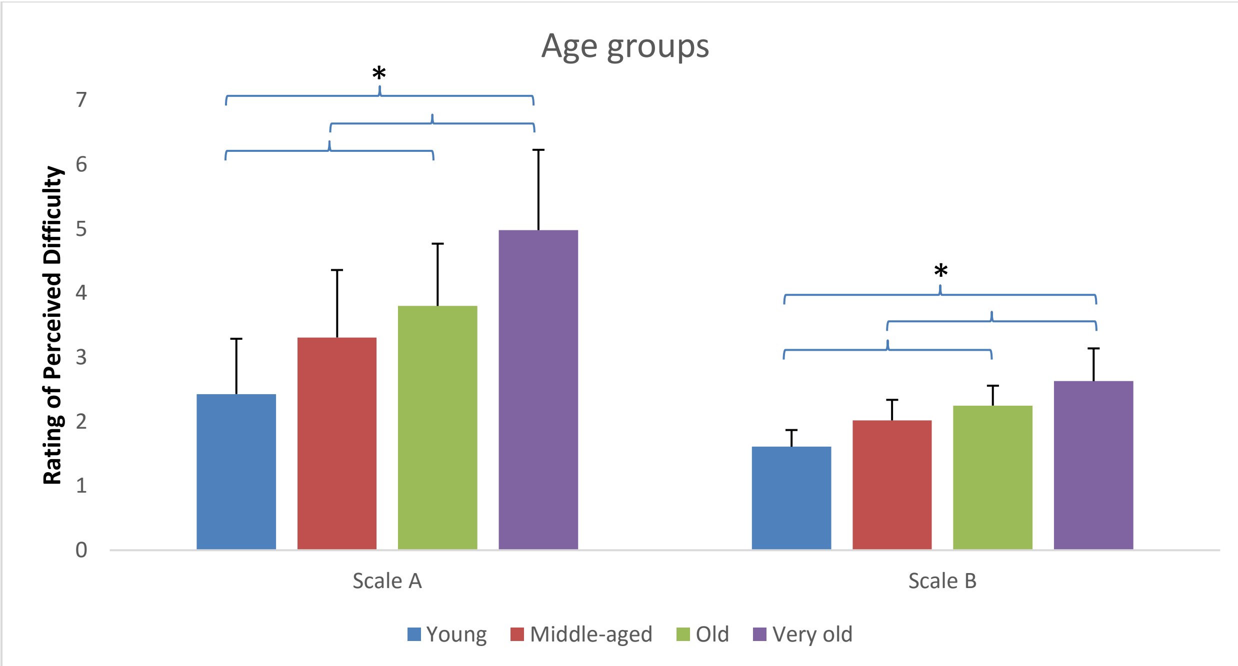


Figure 5-11: Differences among the age groups (Young, Middle-aged, Old, Very old) on mean change of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

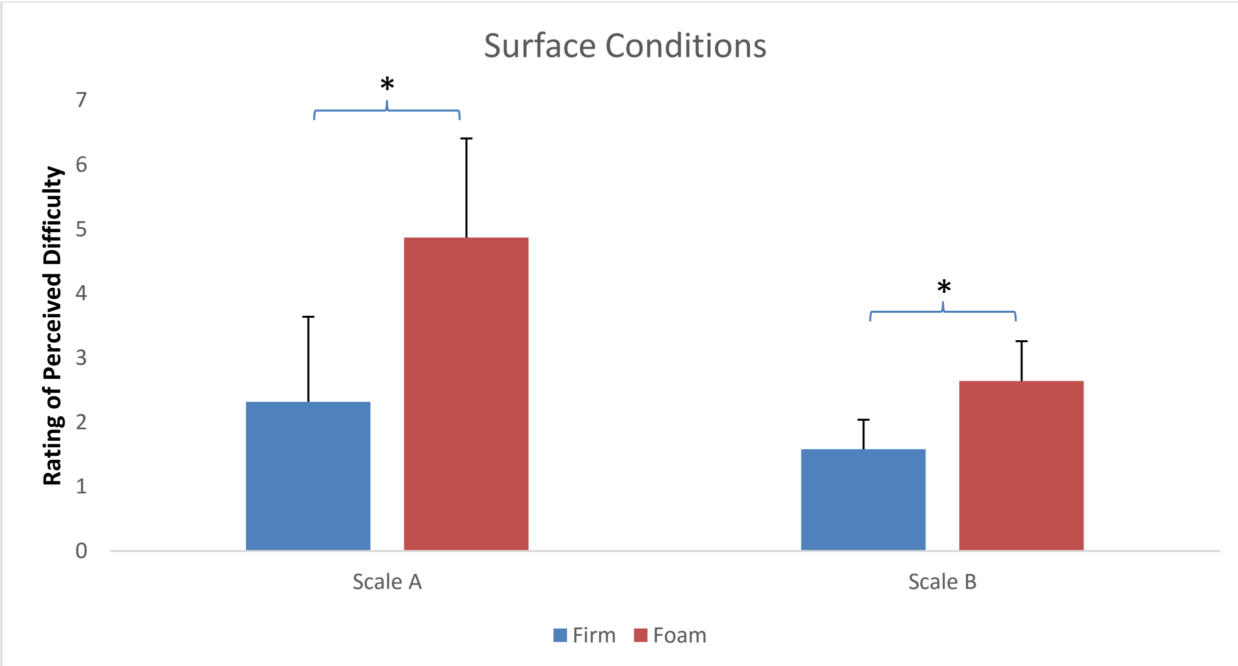


Figure 5-12: Differences between the two types of surface (firm and foam surfaces) on mean of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

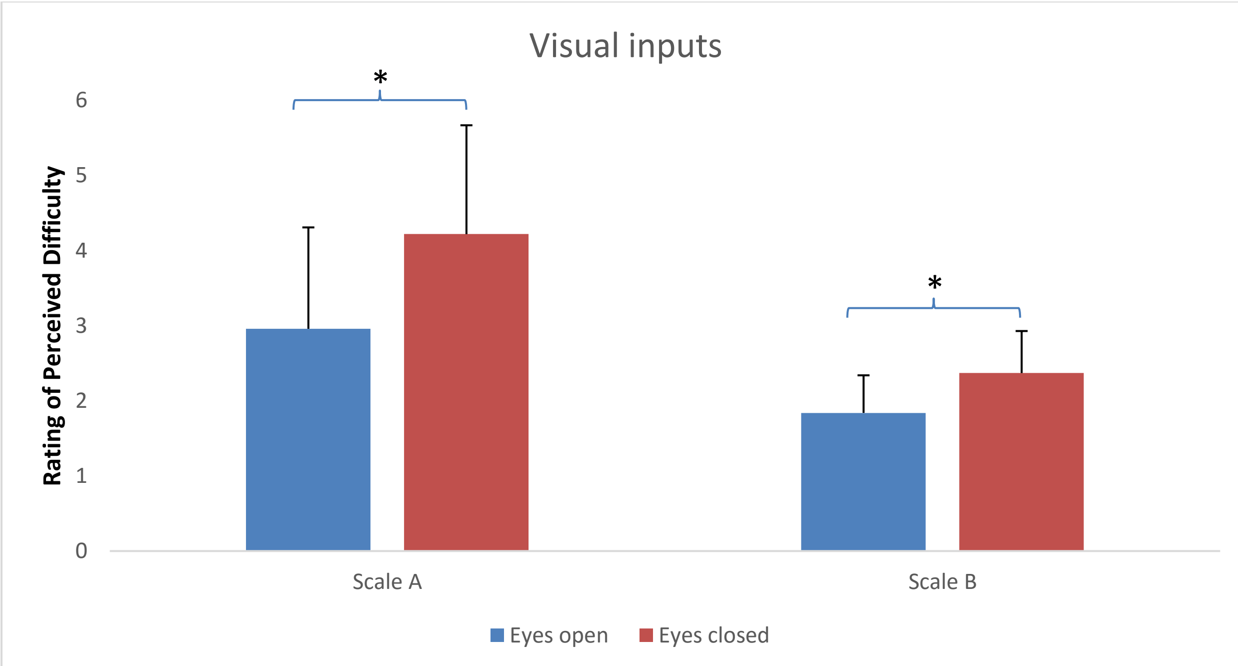


Figure 5-13: Differences between the two types of visual input (eyes open and eyes closed) on mean of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * p < 0.05 difference between pairs.

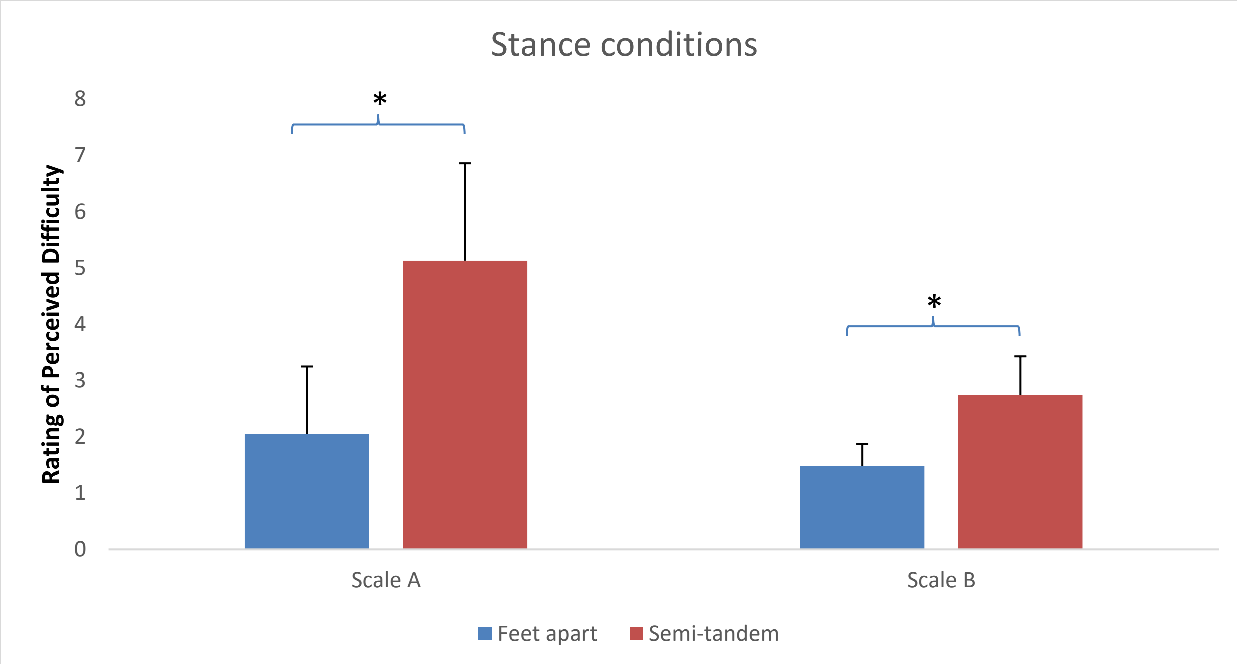


Figure 5-14: Differences between the two types of stance (feet apart and semi-tandem) on mean of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

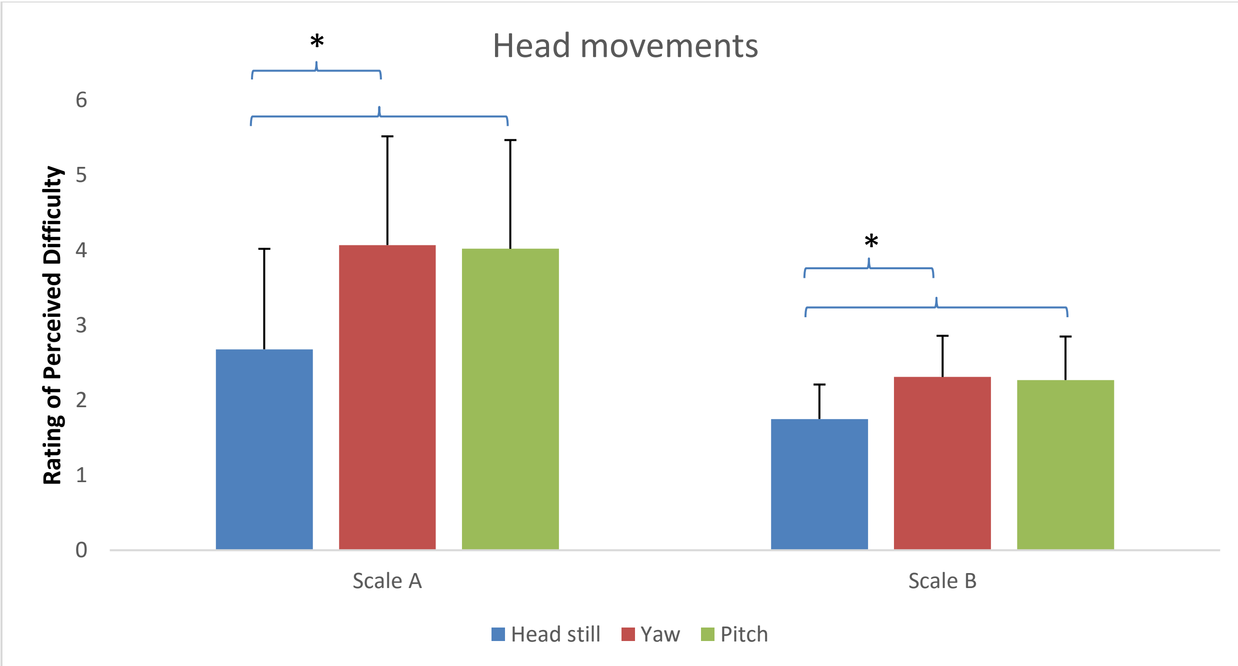


Figure 5-15: Differences among the three head movements (head still, yaw, pitch) on mean of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

5.3.4 Static standing balance exercises sequence

In this study, the 24 static standing balance exercises were ranked in order from the easiest to the most difficult exercises based on subjects' trunk angular velocity in pitch and roll directions (Table 5-9) as it was the most reliable measure, and ratings of perceived difficulty using Scale A and B (Table 5-10). The proposed sequences of exercise progression aim to guide clinicians and researchers in designing and progressing treatment plans. For RMS pitch velocity, eight out of the nine greatest sway values were produced by pitch head movements. Of course, the surface, stance, and visual input had lesser influence on the pitch velocity. With respect to roll velocity, head movement did not seem to matter as much as stance condition and surface. The rating of perceived difficulty scales orders were weighted more toward foam surface, semi-tandem stance, and any type of head movement.

Table 5-9: Exercise sequences based on average of trunk angular velocity measures in pitch and roll directions

Exercise number	Surface	Visual input	Stance	Head movement	RMS pitch velocity
1	Firm	EO	FA	Head still	0.45
7	Firm	EC	FA	Head still	0.52
13	Foam	EO	FA	Head still	0.67
4	Firm	EO	ST	Head still	0.70
2	Firm	EO	FA	Yaw	0.71
10	Firm	EC	ST	Head still	0.86
8	Firm	EC	FA	Yaw	0.90
19	Foam	EC	FA	Head still	0.92
16	Foam	EO	ST	Head still	1.13
5	Firm	EO	ST	Yaw	1.15
14	Foam	EO	FA	Yaw	1.20
11	Firm	EC	ST	Yaw	1.51
20	Foam	EC	FA	Yaw	1.74
22	Foam	EC	ST	Head still	1.79
17	Foam	EO	ST	Yaw	1.98
3	Firm	EO	FA	Pitch	2.03
6	Firm	EO	ST	Pitch	2.18
15	Foam	EO	FA	Pitch	2.48
9	Firm	EC	FA	Pitch	2.50
23	Foam	EC	ST	Yaw	2.62
12	Firm	EC	ST	Pitch	2.67
18	Foam	EO	ST	Pitch	2.93
21	Foam	EC	FA	Pitch	3.08
24	Foam	EC	ST	Pitch	3.68

Exercise Number	Surface	Visual input	Stance	Head movement	RMS roll velocity
1	Firm	EO	FA	Head still	0.17
7	Firm	EC	FA	Head still	0.19
13	Foam	EO	FA	Head still	0.37
3	Firm	EO	FA	Pitch	0.37
9	Firm	EC	FA	Pitch	0.45
4	Firm	EO	ST	Head still	0.46
19	Foam	EC	FA	Head still	0.46
10	Firm	EC	ST	Head still	0.58
15	Foam	EO	FA	Pitch	0.66
2	Firm	EO	FA	Yaw	0.74
21	Foam	EC	FA	Pitch	0.82
6	Firm	EO	ST	Pitch	0.88
14	Foam	EO	FA	Yaw	0.99
8	Firm	EC	FA	Yaw	1.06
5	Firm	EO	ST	Yaw	1.10
12	Firm	EC	ST	Pitch	1.10
16	Foam	EO	ST	Head still	1.11
20	Foam	EC	FA	Yaw	1.31
11	Firm	EC	ST	Yaw	1.49
22	Foam	EC	ST	Head still	1.68
18	Foam	EO	ST	Pitch	1.97
17	Foam	EO	ST	Yaw	2.37
24	Foam	EC	ST	Pitch	2.98
23	Foam	EC	ST	Yaw	3.53

EO: eyes open; EC: eyes closed; FA: feet apart; ST: semi-tandem; RMS: Root Mean Square.

Table 5-10: Exercise sequences based on rating of perceived difficulty Scales A and B

Exercise number	Surface	Visual input	Stance	Head movement	Scale A
1	Firm	EO	FA	Head still	0.44
7	Firm	EC	FA	Head still	0.82
2	Firm	EO	FA	Yaw	1.04
3	Firm	EO	FA	Pitch	1.05
8	Firm	EC	FA	Yaw	1.39
9	Firm	EC	FA	Pitch	1.56
13	Foam	EO	FA	Head still	1.80
4	Firm	EO	ST	Head still	2.30
19	Foam	EC	FA	Head still	2.62
14	Foam	EO	FA	Yaw	2.66
15	Foam	EO	FA	Pitch	2.95
10	Firm	EC	ST	Head still	3.11
6	Firm	EO	ST	Pitch	3.22
5	Firm	EO	ST	Yaw	3.42
20	Foam	EC	FA	Yaw	3.96
16	Foam	EO	ST	Head still	4.12
21	Foam	EC	FA	Pitch	4.32
12	Firm	EC	ST	Pitch	4.50
11	Firm	EC	ST	Yaw	4.92
18	Foam	EO	ST	Pitch	6.17
22	Foam	EC	ST	Head still	6.27
17	Foam	EO	ST	Yaw	6.38
24	Foam	EC	ST	Pitch	8.38
23	Foam	EC	ST	Yaw	8.74

Exercise Number	Surface	Visual input	Stance	Head movement	Scale B
1	Firm	EO	FA	Head still	1.04
7	Firm	EC	FA	Head still	1.08
2	Firm	EO	FA	Yaw	1.08
3	Firm	EO	FA	Pitch	1.12
8	Firm	EC	FA	Yaw	1.16
9	Firm	EC	FA	Pitch	1.19
13	Foam	EO	FA	Head still	1.40
4	Firm	EO	ST	Head still	1.58
14	Foam	EO	FA	Yaw	1.67
19	Foam	EC	FA	Head still	1.72
15	Foam	EO	FA	Pitch	1.78
10	Firm	EC	ST	Head still	1.85
6	Firm	EO	ST	Pitch	1.89
5	Firm	EO	ST	Yaw	1.94
20	Foam	EC	FA	Yaw	2.17
16	Foam	EO	ST	Head still	2.21
21	Foam	EC	FA	Pitch	2.36
12	Firm	EC	ST	Pitch	2.37
11	Firm	EC	ST	Yaw	2.68
22	Foam	EC	ST	Head still	3.10
18	Foam	EO	ST	Pitch	3.13
17	Foam	EO	ST	Yaw	3.29
24	Foam	EC	ST	Pitch	4.30
23	Foam	EC	ST	Yaw	4.50

EO: eyes open; EC: eyes closed; FA: feet apart; ST: semi-tandem.

A hierarchical cluster analysis (HCA) was performed to categorize the exercises across all age groups into five clusters based on RMS tilt velocity or rating of perceived difficulty to help physical therapists to establish a scientific basis for exercise progression. For the sway measures, exercises 23 and 24 were excluded from the cluster analysis for the postural sway measures because of the high percentage of missing data due to their difficulty and were categorized into the highest category. All other exercises (1-22) were classified into the other four clusters (see Table 5-11).

Table 5-11: Exercise clusters based on rating scores and trunk angular velocity measures in pitch and roll directions

Exercise number	Surface	Visual input	Base of support	Head movement	Scale A (cluster)	Scale B (cluster)	RMS pitch velocity (cluster)	RMS roll velocity (cluster)
1	Firm	EO	FA	Head still	0.44 (1)	1.04 (1)	0.45 (1)	0.17 (1)
7	Firm	EC	FA	Head still	0.82 (1)	1.08 (1)	0.52 (1)	0.19 (1)
2	Firm	EO	FA	Yaw	1.04 (1)	1.08 (1)	0.71 (1)	0.74 (2)
3	Firm	EO	FA	Pitch	1.05 (1)	1.12 (1)	2.03 (3)	0.37 (1)
8	Firm	EC	FA	Yaw	1.39 (1)	1.16 (1)	0.90 (2)	1.06 (3)
9	Firm	EC	FA	Pitch	1.56 (1)	1.19 (1)	2.50 (4)	0.45 (1)
13	Foam	EO	FA	Head still	1.80 (1)	1.40 (2)	0.67 (1)	0.37 (1)
4	Firm	EO	ST	Head still	2.30 (2)	1.58 (2)	0.70 (1)	0.46 (1)
19	Foam	EC	FA	Head still	2.62 (2)	1.72 (2)	0.93 (2)	0.46 (1)
14	Foam	EO	FA	Yaw	2.66 (2)	1.67 (2)	1.20 (2)	0.99 (3)
15	Foam	EO	FA	Pitch	2.95 (2)	1.78 (2)	2.48 (4)	0.66 (2)
10	Firm	EC	ST	Head still	3.11 (2)	1.85 (2)	0.86 (2)	0.58 (2)
6	Firm	EO	ST	Pitch	3.22 (2)	1.89 (2)	2.18 (3)	0.88 (2)
5	Firm	EO	ST	Yaw	3.42 (2)	1.94 (2)	1.15 (2)	1.10 (3)
20	Foam	EC	FA	Yaw	3.96 (3)	2.17 (3)	1.74 (3)	1.31 (3)
16	Foam	EO	ST	Head still	4.12 (3)	2.21 (3)	1.13 (2)	1.11 (3)
21	Foam	EC	FA	Pitch	4.32 (3)	2.36 (3)	3.08 (4)	0.82 (2)
12	Firm	EC	ST	Pitch	4.50 (3)	2.37 (3)	2.67 (4)	1.11 (3)
11	Firm	EC	ST	Yaw	4.92 (3)	2.68 (3)	1.51 (3)	1.49 (3)
18	Foam	EO	ST	Pitch	6.17 (4)	3.13 (4)	2.93 (4)	1.97 (4)
22	Foam	EO	ST	Head still	6.27 (4)	3.10 (4)	1.79 (3)	1.68 (4)
17	Foam	EC	ST	Yaw	6.38 (4)	3.29 (4)	1.98 (3)	2.37 (4)
24	Foam	EC	ST	Pitch	8.38 (5)	4.30 (5)	3.68 (5)	2.98 (5)
23	Foam	EC	ST	Yaw	8.74 (5)	4.50 (5)	2.62 (5)	3.53 (5)

	Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5

EO: eyes open; EC: eyes closed; FA: feet apart; ST: semi-tandem; RMS: Root Mean Square.

The clusters for the rating of perceived difficulty scales were similar. For RMS pitch velocity, exercises with head pitch movements were concentrated into cluster 4. Meanwhile the RMS roll velocity cluster reflected the rating of perceived difficulty scales, although some yaw head movement exercises were placed into more difficult clusters.

A hierarchical cluster analysis was performed to categorize the exercises for each age group into five categories based on rating of perceived difficulty scores and postural sway measures (RMS of trunk tilt velocity in pitch and roll directions). Exercises number 23 and 24 were excluded from the cluster analysis for the middle-aged, old, very old groups for the postural sway measures section because of the high percentage of missing data due to their difficulty and were categorized into the most difficult category. All other exercises (1-22) were divided into the other four clusters (see table 5-12).

Table 5-12: Exercises categories for age groups based on trunk angular velocity measures

	RMS pitch velocity					RMS roll velocity			
Exercise number	Young	Middle-aged	Old	Very old	Exercise number	Young	Middle-aged	Old	Very old
1	0.50 (1)	0.34 (1)	0.45 (1)	0.52 (1)	7	0.21 (1)	0.14 (1)	0.15 (1)	0.24 (1)
7	0.50 (1)	0.42 (1)	0.46 (1)	0.71 (1)	1	0.21 (1)	0.14 (1)	0.16 (1)	0.19 (1)
13	0.62 (1)	0.53 (1)	0.65 (1)	0.87 (1)	13	0.35 (1)	0.30 (1)	0.33 (1)	0.48 (1)
4	0.66 (1)	0.58 (1)	0.64 (1)	0.94 (1)	19	0.40 (1)	0.45 (1)	0.40 (1)	0.59 (1)
2	0.68 (1)	0.61 (1)	0.72 (1)	0.83 (1)	4	0.42 (1)	0.37 (1)	0.42 (1)	0.64 (1)
10	0.74 (1)	0.76 (2)	0.77 (1)	1.18 (1)	3	0.44 (1)	0.34 (1)	0.35 (1)	0.35 (1)
19	0.78 (1)	0.87 (2)	0.85 (1)	1.23 (1)	10	0.51 (1)	0.50 (1)	0.55 (1)	0.79 (1)
8	0.82 (1)	0.76 (2)	0.87 (1)	1.16 (1)	9	0.54 (1)	0.43 (1)	0.39 (1)	0.42 (1)
16	0.90 (1)	0.93 (2)	1.18 (2)	1.56 (2)	15	0.62 (1)	0.57 (1)	0.65 (1)	0.81 (1)
5	0.99 (1)	0.97 (2)	1.09 (2)	1.58 (2)	6	0.72 (2)	0.78 (2)	0.90 (2)	1.13 (2)
14	1.01 (1)	1.06 (2)	1.18 (2)	1.59 (2)	21	0.74 (2)	0.78 (2)	0.80 (2)	0.97 (2)
11	1.20 (2)	1.51 (3)	1.52 (2)	1.93 (2)	2	0.78 (2)	0.63 (1)	0.83 (2)	0.73 (1)
22	1.22 (2)	1.63 (3)	2.03 (3)	2.50 (3)	16	0.89 (2)	0.91 (2)	1.14 (2)	1.53 (2)
20	1.30 (2)	1.74 (3)	1.64 (2)	2.34 (3)	12	0.91 (2)	1.03 (2)	1.17 (2)	1.36 (2)
17	1.48 (2)	1.84 (3)	2.00 (3)	2.85	14	0.94 (2)	0.83 (2)	1.03 (2)	1.18 (2)
6	2.06 (3)	2.10 (3)	2.20 (3)	2.37 (3)	5	0.95 (2)	0.92 (2)	1.12 (2)	1.43 (2)
3	2.26 (3)	1.97 (3)	2.16 (3)	1.71 (2)	20	1.09 (3)	1.21 (3)	1.49 (3)	1.46 (2)
18	2.43 (3)	2.90 (4)	3.32 (4)	3.24 (4)	8	1.10 (3)	0.88 (2)	1.19 (2)	1.06 (2)
12	2.55 (3)	2.48 (4)	2.89 (3)	2.80 (4)	11	1.14 (3)	1.45 (3)	1.51 (3)	1.96 (3)
15	2.68 (4)	2.25 (3)	2.56 (3)	2.42 (3)	22	1.28 (3)	1.68 (3)	1.87 (4)	1.99 (3)
21	2.84 (4)	2.87 (4)	3.30 (4)	3.33 (4)	18	1.60 (4)	2.08 (4)	2.12 (4)	2.19 (3)
9	2.91 (4)	2.54 (4)	2.44 (3)	2.04 (2)	17	1.84 (4)	2.28 (4)	2.46 (4)	3.12 (4)
23	2.49 (5)	2.63 (5)	2.96 (5)	1.74 (5)	24	2.92 (5)	3.38 (5)	3.02 (5)	1.90 (5)
24	3.22 (5)	3.69 (5)	4.46 (5)	3.38 (5)	23	3.69 (5)	3.26 (5)	3.63 (5)	2.62 (5)

	Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5

RMS: Root Mean Square.

For RMS pitch velocity, more exercises were in cluster 1 for the young group and for the middle-aged group, there were less exercises were in cluster 1. Overall, the order of the exercise difficulty was not the same between groups. With respect to RMS roll velocity, the clusters of exercise difficulty were relatively similar between groups.

Table 5-13: Exercises categories for age groups based on rating of perceived difficulty scales

Exercise number	Rating of perceived difficulty (Scale A)				Rating of perceived difficulty (Scale B)			
	Young	Middle-aged	Old	Very old	Young	Middle-aged	Old	Very old
1	0.12 (1)	0.17 (1)	0.60 (1)	0.90 (1)	1.01 (1)	1.00 (1)	1.03 (1)	1.10 (1)
7	0.47 (1)	0.57 (1)	0.75 (1)	1.53 (1)	1.01 (1)	1.00 (1)	1.03 (1)	1.30 (1)
2	0.74 (1)	0.77 (1)	1.00 (1)	1.72 (1)	1.01 (1)	1.02 (1)	1.07 (1)	1.25 (1)
3	0.81 (1)	0.72 (1)	1.20 (1)	1.52 (1)	1.03 (1)	1.07 (1)	1.10 (1)	1.29 (1)
8	1.15 (1)	1.08 (1)	1.23 (1)	2.14 (1)	1.09 (1)	1.03 (1)	1.08 (1)	1.44 (1)
9	1.25 (1)	1.27 (1)	1.35 (1)	2.42 (1)	1.10 (1)	1.08 (1)	1.05 (1)	1.52 (1)
13	1.03 (1)	1.20 (1)	1.98 (2)	3.11 (1)	1.10 (1)	1.23 (2)	1.55 (2)	1.74 (1)
4	1.21 (1)	1.77 (2)	2.40 (2)	3.98 (2)	1.19 (2)	1.37 (2)	1.78 (2)	2.03 (2)
19	1.60 (2)	2.32 (2)	2.60 (2)	4.08 (2)	1.25 (2)	1.65 (2)	1.85 (2)	2.18 (2)
14	1.62 (2)	2.12 (2)	2.90 (2)	4.13 (2)	1.19 (2)	1.50 (2)	1.97 (2)	2.10 (2)
10	1.81 (2)	2.72 (2)	3.33 (2)	4.75 (2)	1.32 (2)	1.65 (2)	2.02 (2)	2.49 (2)
15	1.93 (2)	2.38 (2)	3.18 (2)	4.46 (2)	1.26 (2)	1.62 (2)	2.00 (2)	2.33 (2)
6	1.68 (2)	2.52 (2)	3.82 (2)	5.09 (2)	1.21 (2)	1.63 (2)	2.17 (3)	2.63 (3)
5	1.99 (2)	2.68 (2)	3.60 (2)	5.62 (3)	1.35 (2)	1.70 (2)	2.00 (2)	2.78 (3)
20	2.57 (3)	3.80 (3)	3.78 (2)	5.87 (3)	1.49 (3)	2.12 (3)	2.29 (3)	2.88 (3)
16	2.46 (3)	3.87 (3)	4.50 (3)	5.89 (3)	1.51 (3)	2.18 (3)	2.50 (3)	2.72 (3)
21	2.88 (3)	4.00 (3)	4.62 (3)	5.98 (3)	1.69 (3)	2.30 (3)	2.47 (3)	3.06 (3)
12	2.90 (3)	4.08 (3)	4.58 (3)	6.66 (4)	1.63 (3)	2.15 (3)	2.55 (3)	3.23 (3)
11	3.01 (3)	4.64 (3)	5.09 (3)	7.19 (4)	1.76 (3)	2.57 (3)	2.83 (3)	3.68 (4)
18	4.06 (4)	6.27 (4)	7.04 (4)	7.60 (4)	2.19 (4)	3.05 (4)	3.53 (4)	3.88 (4)
22	4.21 (4)	6.43 (4)	6.97 (4)	7.74 (4)	2.21 (4)	3.12 (4)	3.45 (4)	3.74 (4)
17	4.25 (4)	6.27 (4)	7.04 (4)	8.25 (4)	2.28 (4)	3.23 (4)	3.63 (4)	4.15 (4)
24	6.88 (5)	8.68 (5)	8.67 (5)	9.49 (5)	3.67 (5)	4.44 (5)	4.48 (5)	4.71 (5)
23	7.61 (5)	9.01 (5)	9.00 (5)	9.51 (5)	3.95 (5)	4.65 (5)	4.59 (5)	4.88 (5)

	Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5

The clusters for the rating of perceived difficulty scales for age groups were relatively similar between groups in both scales A and B.

5.4 DISCUSSION

The present study was designed to determine the effect of age and exercise conditions (surface type, visual input, stance type, and head movement) on quantitative postural measures and ratings of perceived difficulty. The results of this study showed age-related postural sway changes which were evident by increases in the quantitative postural measures as age increased, consistent with other research (Abrahamova & Hlavacka, 2008; Baloh et al., 1998; Era et al., 2006; Gill et al., 2001; Liaw et al., 2009; Rosenhall & Rubin, 1975; Sheldon, 1963). While all sway measures were significantly different between the youngest group (18-44 y/o) and the very old group (75-85 y/o), differences between consecutive pairs of age groups were found less frequently. In particular, the lack of significant differences among the youngest three groups is in contrast with findings of previous research, (Abrahamova & Hlavacka, 2008; Era et al., 2006; Gill et al., 2001; Liaw et al., 2009) which found differences among younger adult groups. One possible explanation for these results may be due to the amount and type of chosen balance tests included in this study.

Many more exercises, of varying difficulties, could have resulted in increased variance, making it more difficult to find between group differences. In this study, the sway data were combined and analyzed for 24 balance tests, whereas in most of other studies, age groups were compared for individual tests (Abrahamova & Hlavacka, 2008; Era et al., 2006; Gill et al., 2001; Liaw et al., 2009). The results reported by Era et al. showed a significant difference between young and middle-aged groups when comparing the amount of sway during standing on firm surface with eyes open and feet apart, standing on firm surface with eyes closed and feet apart, and standing on firm surface with eyes open and semi-tandem stance. Similarly, Abrahamova et al. found a significant difference between young and middle-aged groups on the amount of sway when subjects stood on firm and foam surfaces with eyes open. In this study we analyzed a subsample of similar exercises included in this study (1, 4, 7, and 13), and we found only one significant difference between the young and middle-aged groups when they performed exercise No. 1 (standing on firm surface with eyes open, feet apart, and head still) in the angular velocity in pitch direction.

The results of rating of perceived difficulty agree with the findings of sway measures, in which the rating of perceived difficulty increased as age increased from the youngest to the oldest age group. Furthermore, the observed mean scores of the ratings of perceived difficulty of Scale A and B were significantly different between more groups, compared to the sway parameters, which indicates that different age groups perceived the difficulty of balance exercises differently although the sway measures were not significantly different between some of the groups. The discrepancy between sway parameters and rating of perceived difficulty scales in demonstrating differences among the different age groups may indicate that subjects are considering other factors besides their sway output to rate their difficulty. These factors may include strain, discomfort and/or fatigue, and negative emotional factors that are experienced during performance of balance exercises (Borg, 1982; Noble & Robertson, 1996).

The results confirmed the hypothesis that the main experimental conditions (surface type, visual input, stance condition, and head movement) would increase sway measures and rating of perceived difficulty. The present findings are consistent with other research which found an increase in body sway with alteration of sensory information through decreasing proprioception information by standing on foam (Abrahamova & Hlavacka, 2008; Cohen et al., 1996; Gill et al., 2001), lack of visual information by closing eyes (Abrahamova & Hlavacka, 2008; Cohen et al., 1996; Era et al., 2006; Gill et al., 2001; Hytonen, Pyykko, Aalto, & Starck, 1993), and narrowing the base of the support by standing in semi-tandem stance (Era et al., 2006).

Although yaw and pitch head movements were different in all sway measures, yaw head movement produced higher sway values in the measures of the mediolateral direction compared with the anteroposterior direction. In contrast, pitch head movements generated higher sway values in the pitch and anteroposterior direction compared with roll plane and mediolateral direction. However, participants across all age groups didn't perceive the difficulty of these two conditions differently. This discrepancy between the findings of the quantitative postural measures and rating of perceived difficulty may be due to the fact that we compared how the subjects globally perceived the difficulty of exercises, while the sway measures were collected in single planes separately. It is possible that the combined resultant of the sway measures in the AP and ML directions may not have produced a difference between the trials with different head movements.

In addition, the main experimental factors (surface type, visual input, stance condition, and head movement) increased the rating of perceived difficulty and is consistent with the results of the sway measures analysis. Ratings of Scale A and B were significantly higher when decreasing proprioception information by standing on foam, lack of visual information by closing eyes, narrowing base of support by standing in semi-tandem stance, and altering vestibular function through head movements.

There was an interaction between age and exercise condition on quantitative postural measures, except for the interaction between age and visual inputs. The very old group had greater increases in sway compared with the other groups as the conditions become more difficult with standing on foam, narrowing base of support, and moving the head. This age effect should be accounted for when designing and progressing exercise programs. These results show the importance of assessing these conditions (foam, semi-tandem, and yaw and pitch head movements) in studies aiming to explore the effect of age on balance or in balance training programs aiming to increase the challenge level of the exercises. In contrast, closing eyes didn't seem to distinguish between groups compared to eyes open.

Trunk angular velocity parameters and ratings of perceived difficulty of 24 static standing balance exercises were analyzed to establish a scientific basis for exercise progression that can be used in balance rehabilitation programs. One of the sequences was developed based on the ratings of perceived difficulty Scales A and B, which were overall similar to each other. On the contrary, the sequences based on tilt velocities were different. A few exercises, like exercise No. 1, 7, and 13 resulted in less sway velocity in both pitch and roll directions and were ranked at the same levels in the two sequences, whereas, other exercises resulted in less sway velocity in the yaw direction but high sway velocity in the pitch direction. For instance, exercise 16 produced less sway velocity in the pitch direction compared with the yaw direction; as a result, it was ranked in a lower cluster of difficulty in the sequence based on pitch velocity whereas it was ranked in a higher cluster of difficulty in the sequence based on roll velocity.

In comparison of sequences developed based on sway measures and ratings of perceived difficulty, all six exercises that were ranked higher on the sequence based on the trunk angular velocity in the pitch direction compared to the rating of perceived difficulty were exercises with pitch head movement. Conversely, all four exercises that were ranked higher on the sequence based on the trunk angular velocity in the roll direction compared to the rating of perceived difficulty were all exercises with yaw head movement. As has been noted, head movements especially in the pitch direction may cause an amount of sway that may not be perceived necessarily as difficult. Active pitch head movement results in a high amount of sway in the pitch direction which may overestimate the difficulty exercises with pitch head movement. The amount of sway that was produced by some exercises with semi-tandem stance may have under-represented their ratings of perceived difficulty. For this reason, it may be appropriate to consider measuring sway in the ML direction in order to quantify the difficulty of exercises with semi-tandem stance. Additionally, these findings illustrate the importance of asking subjects about how they perceive the difficulty of any task they perform.

Using the rating of perceived difficulty to distribute the 24 exercises into the five categories for each group revealed relatively similar distributions except that six exercises were categorized in different levels for different age groups, and only were off by one cluster level. In contrast, the use of trunk angular velocity parameters in the pitch and roll directions revealed relatively different distributions of the exercises for the different age groups, with 15 exercises categorized into different levels of difficulty based on trunk angular velocity in the pitch direction and were off by 2 levels in some cases. Only 5 exercises were categorized in different levels of difficulty based on trunk angular velocity in the roll direction and were off only by 1 level. A higher disparity exists in rating the difficulty of exercises based on sway parameters between age groups especially in the pitch direction compared with the ratings based on the perceived difficulty; this higher disparity may be because subjects in different age groups may have used different corrective strategies such as a hip strategy, especially with older subjects during the most challenging tasks (Cohen et al., 1996; Liaw et al., 2009).

The findings of the exercise progression sequences are consistent with the American College of Sports Medicine (ACSM) recommendations of appropriate progression of balance exercises, in which reducing the base of support changing from feet apart to semi-tandem stance, changing the visual input from eyes open to eyes closed, or changing the surface compliance from firm surface to foam surface is more challenging and decrease postural stability (Pescatello & American College of Sports Medicine., 2014). Additionally, the findings of this study seem to be consistent to a large extent with Klatt et al.'s work which developed a conceptual framework of progression for different balance exercise categories including static standing balance exercises (Klatt et al., 2015). In Klatt's work, it was suggested that limiting base of support by standing in semi-tandem stance was less challenging than closing eyes while holding other exercise conditions constant, which contradicts with our findings, according to the sway velocity measures as well as ratings of perceived difficulty. Alternatively, our subjects perceived standing in semi-tandem stance with eyes open to be more challenging than eyes closed with feet apart. Additionally, Klatt et al. reported that exercises with head movements regardless of the vision condition to be more difficult than standing in semi-tandem with head still, which is consistent with how our subjects perceived these exercises. However, we found that exercises with head movements regardless of the vision condition produced less sway velocity compared with standing in semi-tandem with head still. Similarly, the findings of our study relatively match Muehlbauer et al.'s work where they assessed the relative difficulty of 12 balance exercises in order to develop a progression sequence, starting from the exercise that produced the least COP displacement to the exercise that produced the most COP displacement (Muehlbauer et al., 2012). The results of our study are also consistent with the results of Farlie's study where they found that the visually observed sway increased with increasing the difficulty of the exercise, and they also found that subjects' perceived description of the exercise difficulty matched very well the intensity levels of the exercises (Farlie et al., 2016).

Clinicians can take advantage of the proposed sequences of exercise progression to select an appropriate exercise for their clients based on their age and health status as well as they can diversify among the proposed exercises in each level of the five exercise categories that were divided based on their difficulty. Clinicians can use the developed rating of perceived difficulty scales to estimate the intensity of each exercise in situations when sway cannot be measured. The sway measures collected could be used to set ranges of normal limits of sway for different age groups, and can be used as reference normative data when comparing patients' data to others. Finally, these values could be used for augmented sensory feedback devices to set the threshold limits when a feedback can be provided.

5.5 LIMITATIONS

Each study visit required one hour and forty-five minutes and even longer for older adults which may have caused fatigue. However, randomizing the testing conditions during the experiment sessions and visits for each subject and providing rest breaks every three exercises hopefully eliminated fatigue.

Although subjects practiced the head movement in yaw and pitch directions with a laser light attached to the head before they started the experiment, the laser light wasn't used during the experiment and subjects may not have had a good control over the range of head movement during exercises with yaw and pitch head movements. Due to this limitation, subjects may have decreased their range or the speed of head movement in order to maintain their balance.

5.6 CONCLUSION

Postural sway measures and ratings of perceived difficulty were able to demonstrate age, surface, vision, stance, head movement effects. Quantitative sway measures and ratings of perceived difficulty can be used to prescribe intensity of balance exercises and guide progression during rehabilitation.

6.0 PERCEPTUAL AND SWAY MEASURES OF BALANCE IN INDIVIDUALS WITH VESTIBULAR DISORDERS

6.1 INTRODUCTION

Balance is defined as the ability to maintain the upright position during static stance or dynamic activities such as walking or running. Body balance while performing various activities depends on the sensory information received from the eyes, sensory receptors in joints and muscles, and vestibular apparatus (Day et al., 2002; Dozza et al., 2005; Horak, 2006; Kerber et al., 2006; Lichtenstein et al., 1988; Lord et al., 1991a; Lord & Ward, 1994; Ring et al., 1989; Rowell, Shepherd, & American Physiological Society (1887-), 1996). Balance disorders due to aging or disease and injury within the central nervous system or peripheral balance organs may lead eventually to falling (N. B. Alexander, 1994). Falling is one of the leading causes of serious injuries or even death among older people (Tinetti et al., 1995; Tinetti & Williams, 1998) Falls cost the medical care system in the USA about 30 billion dollars in 2010 (Stevens et al., 2006b).

Approximately 65% of older people who fall have balance disorders (Tinetti et al., 1988) and among those with balance problems, approximately 50% have vestibular disorders (Overstall et al., 1977). Unilateral vestibular hypofunction is defined as a reduction of more than 25% of the caloric response in one ear compared to the other during caloric testing (Jongkees et al., 1962). Two-thirds to three-quarters of older adults who have had fall-related hip or wrist fractures were found to have asymmetrical vestibular function (Kristinsdottir et al., 2000; Kristinsdottir et al., 2001).

The vestibular system is one of the peripheral sensory systems that plays an important role in maintaining balance. The vestibular system in particular helps to coordinate eye movements during head movement and to control balance during upright stance and walking by facilitating contraction of the appropriate lower limb muscles in order to prevent falling.

Identification of the risk factors of falling has directed the clinical interventions to reduce the number of future falls (Hilliard et al., 2008). An increase in postural sway has been reported to be one of the predictors of falling among older adults (Berg et al., 1992). Increased postural sway has been reported in many studies to be associated with deteriorated vestibular function (Kerber et al., 2006; Lord & Ward, 1994; Serrador et al., 2009). Vestibular hypofunction may lead ultimately to increased body sway and risk of falling (Stevens et al., 2006b). People with per. People with peripheral vestibular dysfunction may restrict their activities and reduce their participation in daily life activities (Giray et al., 2009).

Since the early 1940s, vestibular rehabilitation programs have been utilized to enhance vestibular compensation of impaired function caused by central and/or peripheral vestibular disorders (Cawthorne, 1946). Vestibular rehabilitation is now widely accepted. Vestibular rehabilitation is comprised of group of exercises techniques designed to stimulate central nervous system compensation through adaptation, habituation, and compensation approaches in order to reduce symptoms and improve balance function. Vestibular rehabilitation resolves symptoms by enabling the central nervous system to adapt to the asymmetries in peripheral vestibular responses (Brodovsky & Vnenchak, 2013; Horak et al., 1992). Habituation exercises have been found to be helpful in retraining the CNS to recognize correct signals coming from the intact vestibular signals as well as other sensory modalities and ignore the false signals from the disabled labyrinth through repeating movements that provoke symptoms (Brodovsky & Vnenchak, 2013). Compensation exercises are developed to employs alternative modalities (e.g. visual and/or somatosensory) to substitute the loss of vestibular function (Halmagyi, Weber, & Curthoys, 2010; B. I. Han et al., 2011; Herdman, 1998). A recent Cochrane review that included 27 high-quality randomized studies suggested there was moderate to strong evidence that vestibular rehabilitation is safe and effective in treating unilateral peripheral vestibular symptoms (Hillier & McDonnell, 2011). According to the vestibular rehabilitation practice guideline for peripheral vestibular hypofunction, there is strong evidence that vestibular rehabilitation is beneficial for people with unilateral and bilateral vestibular hypofunction (Hall et al., 2016).

Standing balance exercises are prescribed for people with vestibular disorders who have difficulty controlling posture. Different exercises can be created by modifying the size of the base of support, altering the visual inputs, changing surface compliance, or performing exercises in different postural positions such as sitting or standing. A randomized control trial by Vereeck et al. incorporated gaze stability and balance exercises for patients after acoustic neuroma resection (young and older) and general instructions for the control group (young and older). Older adults in the experimental group had improvements in most of the balance tests such as standing balance, Timed Up and Go test, tandem gait, and the Dynamic Gait Index (DGI) compared to the older adults in the control group. In contrast, no significant difference was found between the younger adult groups (Vereeck et al., 2008). Similarly, Herdman et al. used vestibular adaptation exercises with patients after acoustic neuroma resection and found improvements in peak-to-peak AP sway. The exercises included in this study were turning head right and left or up and down while standing or sitting (Herdman et al., 1995).

A number of studies have developed exercise progression patterns which contributed to decreasing symptoms and increasing function for persons with vestibular disorders. In persons with bilateral vestibular hypofunction, investigators developed a progression of eye and head movement exercises (Herdman et al., 2007). They increased the number of repetitions of the exercises during the day and the duration of exercise overtime. Then, they placed the visual target in more complex visual backgrounds. The treatment group had greater improvements with dynamic visual acuity and decreased symptoms compared to a placebo exercise group (Herdman et al., 2007).

In a case report study, Gill-Body et al. documented a vestibular rehabilitation program for two older adults with unilateral and bilateral vestibular hypofunction. The program included balance exercises that were distributed over a period of 8 weeks into three phases with various levels of difficulty from easier to harder. The first phase included static standing on a firm surface with eyes open and closed and feet together with arms outstretched and a book on head, walking with narrowed base of support and eyes open, marching in place slowly with eyes open, and active head movement in yaw, pitch, and roll planes. In the second phase, exercises were progressed to standing in semi-tandem stance with eyes open and closed and arms close to the body with the book on their head, standing on a foam surface with eyes open and book on head, walking with a normal and narrow base of support with eyes open and a book on head, and active head movement in yaw, pitch, and roll planes. In the final phase, exercises were progressed to standing on a foam surface with eyes closed and with and without a book on head, walking with a narrowed base of support with eyes closed and with and without a book on head, walking with a normal base of support with fast head movements, marching in place slowly with eyes open and closed and with and without a book on head, and active head movements in yaw, pitch, and roll planes (Gill-Body et al., 1994).

Alsalaheen et al. did a retrospective study of 104 patients who had been diagnosed with concussion and received vestibular rehabilitation exercises (Alsalaheen et al., 2013). Their aim was to describe the exercises provided by the physical therapist and how they were progressed to make the exercises more challenging. Exercises were classified into five types as follows: eye-head coordination, sitting balance, standing static balance, standing dynamic balance, and ambulation. These exercises were progressed by modifying conditions within each exercise category to make them more challenging. For example, the performance of the VORx1 exercise was progressed by having subjects perform the exercises in sitting, then standing with feet apart, and then standing with feet together, and then standing with feet semi-tandem. The exercise progression conditions included changes in posture position, surface type, base of support, trunk position, arm position, head movement direction, direction of whole body movement, visual input, and a cognitive dual task.

Klatt et al. developed a conceptual framework of progression for different balance exercise categories including static standing balance exercises where they ranked exercises in each category based on the hypothesized difficulty (Klatt et al., 2015). In Klatt's work, decisions were made based on systematized literature review, and focus group discussions that included physical therapists and postural control experts (Klatt et al., 2015).

Despite the evidence for the benefit of vestibular rehabilitation in improving gaze stability and postural control in people with vestibular disorders (Hillier & McDonnell, 2011; Horak et al., 1992), there are no evidence-based guidelines for initial prescription or progression of the intensity of balance exercises (Farlie et al., 2013; Klatt et al., 2015; Pescatello & American

College of Sports Medicine., 2014). This study was performed as part of a larger study to develop evidence for recording balance exercise intensity across a wide variety of exercises, which was conducted in participants without vestibular disorders. The specific purpose of this study was to compare postural sway responses and ratings of perceived difficulty in people with vestibular disorders and with healthy age-matched controls across similar exercises.

6.1.1 Specific aim

Specific aim of the study: To examine the effect of vestibular disorders on the magnitude of trunk tilt and ratings of perceived difficulty during performance of different types of static standing balance exercises.

Hypothesis 1:

Individuals with vestibular disorders will have greater trunk tilt and rating of perceived difficulty during the performance of standing balance exercises compared with healthy age-matched controls.

Hypothesis 2:

Individuals with vestibular disorders will have an increase in trunk tilt and rating of perceived difficulty as static standing balance exercises change from level surface to foam surface, eyes open to eyes closed, head still to yaw movement, and feet apart to semi-tandem stance.

Hypothesis 3:

The increase in magnitude of trunk tilt and rating of perceived difficulty as static stance balance exercises change from: level surface to foam surface, eyes open to eyes closed, head still to yaw movement, and feet apart to semi-tandem stance, will be greater in individuals with vestibular disorders compared with healthy age-matched controls.

6.2 METHODS

6.2.1 Participants

Participants with vestibular disorders were recruited from the Balance Disorders Clinic of the University of Pittsburgh Medical Center. A confirmed diagnosis of peripheral or central vestibular disorder was made by a neurotologist based on caloric testing, rotational chair testing, vestibular evoked myogenic potentials and history. Patients were gender and age (±3 years of age) matched with healthy subjects in a ratio of 1:2. The matched healthy subjects' data were used from the parent study.

Healthy subjects and patients were between the ages of 18 and 85 years old and participating in daily activities independently. Subjects were excluded if they were unable to stand for 3 minutes without rest; had distal sensory loss (unable to complete the Romberg test for 30 seconds and unable to feel a pressure of 4.31 g monofilament applied on two different parts of each foot with eyes closed); had visual acuity worse than 20/40, had a diagnosis of benign paroxysmal positional vertigo (BPPV) (positive Dix–Hallpike test or positive Roll test); had a history of neurological or orthopedic disorders; used an assistive device for ambulation; were pregnant; had excessive weight (BMI > 35); or had cognitive impairment (≤ 25 points on the Montreal Cognitive Assessment). Additionally, healthy subjects were excluded if they had a history of falling 2 times or more within the last 12 months doing activities of daily living; or had a peripheral vestibular disorder (positive head impulse test).

This study was approved by the Institutional Review Board in University of Pittsburgh. All subjects signed the informed consent prior to participating in the study.

6.2.2 Instrumentation

During the performance of the exercises in static standing, subjects stood on a force platform (NeuroTest, NeuroCom, Inc., Clackamas, OR) that measured ground reaction forces at a sampling rate of 100 Hz. An inertial measurement unit (IMU, Xsense Technologies B.V., Enschede, The Netherlands) was mounted on each subject's lower back at the level of iliac crest (L4) to record trunk angular displacement and velocity from vertical and linear acceleration in AP and ML directions at a sampling rate of 100 Hz. The IMU uses a combination of accelerometers, gyroscopes, and a magnetometer.

6.2.3 Experimental procedure

The study is an experimental study using a within-subjects and between groups research design to determine the effect of having vestibular disorder and different exercise conditions on balance. All potential research participants came in for a screening visit. The eligible subjects who met the study criteria were asked to return for a testing visit. The independent variables were the groups (2 levels) and the exercise conditions (i.e. surface - 2 levels; visual input - 2 levels; base of support - 2 levels; and head movement - 2 levels). The different levels of exercise conditions are shown in Table 6-1.

Table 6-1: Chosen conditions of static standing exercises

Exercise category	Surface	Visual input	Base of support	Head movement
Static standing	Level surface Foam surface	Eyes open Eyes closed	Feet apart Semi-tandem	Head still Yaw

6.2.3.1 Screening visit

Consented subjects underwent screening tests to rule out conditions known to adversely affect balance. Screening tests included: Romberg stance (Horak, 1987), lower extremities pressure threshold using monofilaments (Holewski, Stess, Graf, & Grunfeld, 1988), visual acuity (Brien Holden, 2008; Muhammad, Alhassan, & Umar, 2015; World-Health-Organization, 2003), the Montreal Cognitive Assessment - Version 3 (Nasreddine et al., 2005), the Dix–Hallpike Test (Dix & Hallpike, 1952), the supine roll test (Lempert & Tiel-Wilck, 1996), and the head impulse test (Halmagyi & Curthoys, 1988).

Eligible subjects who met the study criteria completed the Activities-specific Balance Confidence Scale (ABC) questionnaire (Powell & Myers, 1995), Functional Gait Assessment (FGA) (Wrisley, Marchetti, Kuharsky, & Whitney, 2004), and gait speed (Steffen, Hacker, & Mollinger, 2002) was recorded prior to the experiment in order to better describe the participants. A more detailed description of the screening tests is in Chapter 3. Moreover, people with vestibular disorders completed the Dizziness Handicap Inventory (DHI) (Jacobson & Newman, 1990) and the self-report of dizziness on visual analog scale (Hall & Herdman, 2006; Toupet et al., 2011).

6.2.3.2 Experimental visit

During the experimental visit, subjects with vestibular disorders and matched healthy subjects were asked to perform two sets of 16 randomized static standing exercises, which were a full-factorial design of the following different conditions: vision (eyes open and eyes closed); surface (firm and foam); base of support (feet apart and semi-tandem); head movements (head still and yaw) as shown in Table 6-2.

Table 6-2: Balance and vestibular exercises

Exercise number	Surface	Visual input	Base of support	Head movement
1	Firm	Eyes open	Feet apart	Head still
2	Firm	Eyes open	Feet apart	Yaw
4	Firm	Eyes open	Semi-tandem	Head still
5	Firm	Eyes open	Semi-tandem	Yaw
7	Firm	Eyes closed	Feet apart	Head still
8	Firm	Eyes closed	Feet apart	Yaw
10	Firm	Eyes closed	Semi-tandem	Head still
11	Firm	Eyes closed	Semi-tandem	Yaw
13	Foam	Eyes open	Feet apart	Head still
14	Foam	Eyes open	Feet apart	Yaw
16	Foam	Eyes open	Semi-tandem	Head still
17	Foam	Eyes open	Semi-tandem	Yaw
19	Foam	Eyes closed	Feet apart	Head still
20	Foam	Eyes closed	Feet apart	Yaw
22	Foam	Eyes closed	Semi-tandem	Head still
23	Foam	Eyes closed	Semi-tandem	Yaw

Participants stood without shoes in order to avoid the confounding effect of wearing different shoes. During conditions of the foam surface, subjects stood on a foam pad (AIREX Balance Pad S34-55) that had a height of 6 cm, length of 51 cm, width of 40 cm (density 55 kg/m^3, compression resistance 20 kPa at 25% compression) and the room's temperature was a median value of 72 Fahrenheit degrees with an interquartile range of 3 degrees during all visits to avoid differences in the foam properties (see Appendix C). During the various base of support stances, subjects were asked to distribute their body weight equally on each foot, and to stand during the feet apart condition with their heel centers 0.17 m apart, with an angle of 14 degrees between the long axes of the feet (McIlroy & Maki, 1997). For the semi-tandem stance position, subjects stood with the front foot touching the medial side of the other foot by a half of a foot length (Lee et al., 2012; Nejc et al., 2010), with the dominant foot in the back. The dominant foot was determined by asking the subjects about the foot that they would use to kick a ball (Gabbard & Hart, 1996). During the eyes closed conditions, subjects wore opaque goggles. During yaw head movements, subjects were instructed to move their head at a frequency of 1 Hz by moving their head to the beat of a metronome (Hall & Herdman, 2006) within a range of 45 degrees in the yaw direction (Jung et al., 2009). To ensure that subjects moved their head for 45 degrees in yaw, they practiced the head movement in this direction with a laser light attached to the head before they started the experiment. However, the laser light was not used during the experiment.

Exercises were performed in a random order that was software-generated. Subjects were instructed to stand as stable as possible with arms at their side (Gill-Body et al., 1994; Gill et al., 2001) during all trials for 35 seconds (Allum et al., 2011; Le Clair & Riach, 1996; Muehlbauer et al., 2012; Rine et al., 2013).

Data collection was stopped if a subject lost their balance according to the following failure criteria: stepped out of position, changed their feet or arms starting position, and/or touched something for support. Subjects were asked to repeat failed trials once in each set if they lost their balance before completing a 25 seconds trial. Subjects were guarded by a physical therapist during all exercises to prevent falling and wore a safety harness which was attached to an anchor point in the ceiling that do not let subject reach the ground in case of a fall incidence. There was a seated rest break for 1 minute after every 3 exercises to avoid fatigue.

In addition, subjects rated their perceived difficulty of each exercise they performed using two different scales. The first scale was a modified rating of perceived difficulty scale based on ratings of perceived exertion scales for aerobic and resistance exercises (Scale A) (Robertson et al., 2004; Robertson et al., 2003) that ranges from 0 to 10, where 0 indicates that the exercise is extremely easy whereas 10 indicates that the exercise is extremely hard (Figure 6-1). The second scale was developed for this study and was anchored with colors and statements (Scale B) (Espy et al., 2015) (Figure 6-2). Scale B had 5 levels ranging from A to E, where A was anchored with the following statement; "I feel completely steady" and E labeled as "I lost my balance". In the statistical analysis, letters from scale B were transformed to numbers as follows; A = 1, B = 2, C = 3, D = 4, and E = 5.

Before starting the experiment, both scales were explained to subjects. They were told that they needed to choose, after each exercise, a number from the 1st scale and a letter from the 2nd scale that indicated the difficulty of maintaining their balance during that exercise. During the experiment, the scales were placed on the sidewall so that subjects could look at them after each exercise.

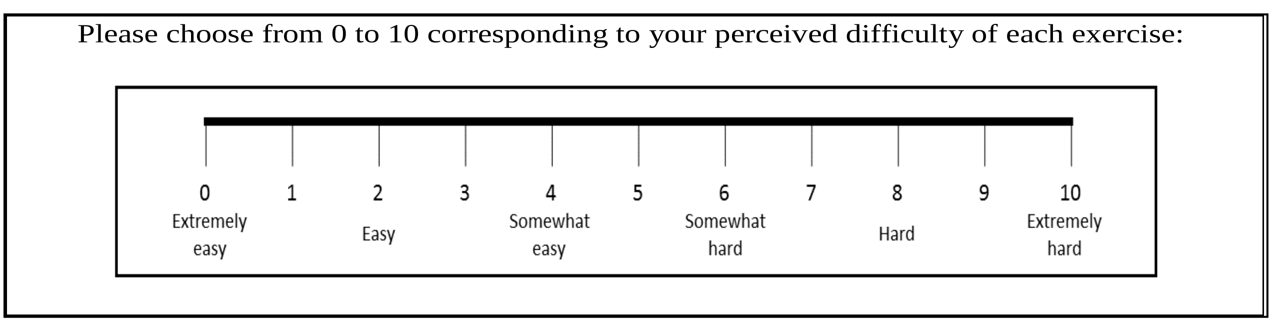


Figure 6-1: Scale A; Rating of perceived difficulty scale, based on OMNI rating of perceived exertion scale (Robertson et al., 2004; Robertson et al., 2003)

Please choose from A to E corresponding to your perceived difficulty of each exercise:	
I feel completely steady	**A**
I feel a little unsteady or off-balance	**B**
I feel somewhat unsteady or like I may lose my balance	**C**
I feel very unsteady or like I definitely will lose my balance	**D**
I lost my balance	**E**

Figure 6-2: Scale B; Rating of perceived difficulty scale, adapted from (Espy et al., 2015)

6.2.4 Outcome measures

Demographic data:

Demographic data including age, gender, medical diagnosis, weight, and height was summarized by descriptive statistics. Additionally, the average scores of the Functional Gait Assessment, Activities-specific Balance Confidence Scale (ABC), gait speed, Dizziness Handicap Inventory (DHI), and self-report of dizziness on visual analog scale for all groups were recorded. In addition, medical diagnoses were reported for people with vestibular disorders.

Sway measures:

Sway measures were recorded during all trials for 35 seconds and the first five seconds of data collection were removed in order to avoid the effect of the subject's initial establishment of balance (O'Sullivan et al., 2009; Rine et al., 2013). Summary measures of trunk sway were calculated from the 30 second time series. The data was low-pass filtered using a second order Butterworth filter with a cut-off frequency of 3 Hz (Dozza et al., 2005; Dozza, Horak, et al., 2007). During the analysis, each trial was plotted individually and inspected visually using MATLAB software to make sure that there were no extraneous movements.

The Root Mean Square (RMS) of the trunk angular displacement and velocity in the pitch and yaw directions, and linear acceleration in the AP and ML directions were calculated and used in the analysis to test the hypotheses. The RMS was calculated as follows:

$$\text{RMS} = \sqrt[2]{\frac{\sum_{i=0}^{n}(a_i^2)}{n}}$$

where a is instantaneous sway value with mean value subtracted, and n is an individual data sample, and N is the total number of samples. The mean value was subtracted before calculating the RMS.

6.2.5 Statistical Analyses

Participants' demographic characteristics were compared between groups using independent samples t-test for dependent variables that were continuous and normally distributed. The Mann-Whitney U test was used to compare differences between the two independent groups when dependent variables were continuous but not normally distributed.

Postural Sway:

A Linear Mixed Model (LMM) was used to test the three hypotheses of the study. The LMM contains fixed effects and random effects. In this study, fixed effects are groups, surface types, visual inputs, stance conditions, and head movements, with a random effect for subjects. Due to the presence of missing data in this study, the decision was made to use LMM as it allows us to evaluate the effects with the presence of having missing data. Additionally, LMM allows inclusion of a random effect, subjects, and assumes that each subject has his/her own intercept value. The LMM was used to explore main effects of the fixed effects and two-way interaction effects between groups and stances, visual inputs, surfaces, and head movements on quantitative postural measures (RMS of trunk tilt in pitch displacement, roll displacement, pitch velocity, roll velocity, AP acceleration, and ML acceleration).

The autoregressive order 1 (AR1) covariance structure was used, which assumes homogeneous variance and unequal covariance between observations on the same subject (Littell et al., 2000). Several different covariance structures were evaluated and AR1 had the best model fits and best reflected the unadjusted means.

An independent t-test was used to compare between people with vestibular disorders and controls on the amount of postural sway for each individual exercise.

The average value of the 2 trials of the dependent variables was used because it was determined that there was no difference between trials. Due to the high incompletion rate of exercise 23, especially for people with vestibular disorders, it was eliminated from the linear mixed model analysis. Normality was tested using the Shapiro–Wilk test. The significance level was $\alpha = 0.05$.

Ratings of Perceived Difficulty:

For rating of perceived difficulty data that was ordinal, the Mann-Whitney U test was used to compare differences in ratings of perceived difficulty between the two groups, and Wilcoxon signed-rank test was used for comparison of two dependent samples (surface conditions, visual inputs, stance conditions, and head movements). The mean value of the 2 trials of the ratings of perceived difficulty from Scales A & B was used.

A Mann Whitney U test was used to compare between people with vestibular disorders and controls on the rating of perceived difficulty scores of Scales A and B for each individual exercise.

6.3 RESULTS

6.3.1 Descriptive statistics:

Eight participants with vestibular disorders met all the eligibility criteria. The eligible participants had a mean age of 56 ± 16 years (four females). The participants with vestibular disorders had normal gait speed (Table 6-3) (Abellan et al., 2009; Hornyak et al., 2012; Lusardi et al., 2003). Five participants were within normal limits of physical functioning and three were below normal based on their scores of the Functional Gait Assessment (FGA) (Walker et al., 2007; Wrisley & Kumar, 2010). In regards to participants' scores on Activities-specific Balance Confidence (ABC) Scale, five participants were within a high level of physical functioning and three had a moderate level of functionality (Huang & Wang, 2009; Myers et al., 1998; Powell & Myers, 1995). Five participants with vestibular disorders were mildly affected by dizziness (0-30 DHI) and two were affected moderately by their dizziness (31-60 DHI) (Whitney, Wrisley, Brown, & Furman, 2004). Four participants with vestibular disorders indicated mild perceived level of dizziness on a visual analog scale before starting the experiment (Table 6-3).

Table 6-3: Demographic characteristics of participants with vestibular disorders

Subject ID #	Subject gender	Age (years)	ABC	Gait Speed (m/s)	FGA	DHI	Dizziness VAS
1	Female	74	97	0.91	26	0	0.00
2	Female	69	59	1.42	24	50	3.13
3	Male	35	94	1.30	26	20	0.60
4	Male	40	98	1.54	30	28	0.00
5	Male	36	96	1.29	30	42	1.93
6	Female	60	69	1.31	22	24	0.00
7	Male	66	92	1.72	29	8	1.08
8	Female	67	74	0.95	22	14	0.00

Table 6-4: Medical diagnoses and vestibular testing

Subject No.	Diagnosis	Vestibular testing
1	Sequelae of a left peripheral vestibulopathy, likely vestibular neuritis	• Abnormal VEMP (bilateral) • Abnormal Caloric test: severely reduced on left side (52%)
2	Ménière's disease	• Abnormal VEMP (right) • Abnormal static positional test: nystagmus intensity of 13 supine deg/sec, 11 head Rt deg/sec, 5 head Lt deg/sec, and 21 Rt lateral deg/sec • Abnormal rotational chair: mild left directional preponderance
3	Left peripheral vestibulopathy	• Abnormal static positional test: nystagmus intensity of 6 deg/sec in supine position • Abnormal Caloric test: 100% RVR on left side • Abnormal rotational chair: mild right directional preponderance
4	Left peripheral vestibulopathy	• Abnormal VEMP (left) • Abnormal rotational chair: mild right directional preponderance
5	Left peripheral vestibulopathy	• Abnormal Caloric test: 100% RVR on left side • Abnormal rotational chair: mild left directional preponderance
6	Right peripheral vestibulopathy	• Abnormal VEMP (right) • Abnormal Caloric test: 100% RVR on right side • Abnormal rotational chair: mild right directional preponderance
7	Dizziness of uncertain etiology with an ongoing vestibular ocular reflex asymmetry	• Abnormal static positional test: nystagmus intensity of 6 deg/sec in Rt lateral position • Abnormal rotational chair: mild right directional preponderance
8	Right peripheral vestibulopathy	• Abnormal VEMP (right) • Abnormal static positional test: nystagmus intensity of 8 deg/sec in head Lt position • Abnormal Caloric test: severely reduced on right side (75%) • Abnormal rotational chair: mild left directional preponderance

VEMP: vestibular-evoked myogenic potentials; Rt: right; Lt: left; deg: degree; sec: second; RVR: reduction of vestibular response.

The participants with vestibular disorders were gender and age matched with healthy subjects in a ratio of 1:2. The matched healthy subjects were recruited from a larger study and had a mean age of 56 ± 16 years (see Table 6-5).

Table 6-5: People with vestibular disorders and controls' demographic characteristics

	Patients (35-74)	Controls (35-76)
	Total (n=8)	Total (n=16)
Age, y, Mean ± SD	56 ± 16	56 ± 16
Gender, female, n (%)	4 (50)	8 (50)
Body Mass Index, kg/m^2, Median (Range)	24.78 (19-30)	26.50 (15-35)
Monofilament, Median (Range)	4.08 (3.61-4.17)	3.84 (3.22-4.17)
Montreal Cognitive Assessment, Median (Range)	28.50 (26-30)	29 (26-30)
The Activities-specific Balance Confidence (ABC) Scale, Median (Range)	93 (59-98)	95 (81-100)
Gait Speed, m/s, Mean ± SD	1.31 ± 0.27	1.35 ± 0.18
Functional Gait Assessment (FGA), Median (Range)	26 (22-30)	28 (19-30)
Dizziness Handicap Inventory (DHI), Median (Range)	22 (0-50)	N/A
Dizziness Visual Analog Scale, Mean ± SD	0.84 (1.16)	N/A

An independent-samples t-test was conducted to compare the age difference between people with vestibular disorders and controls. There was no significant age difference between people with vestibular disorders and controls ($t(22) = 0.009$, $p = 0.99$). Additionally, an independent-samples t-test was conducted to compare gait speed between people with vestibular disorders and controls. There was no significant difference in gait speed for people with vestibular disorders and control groups ($t(22) = 0.53$, $p = 0.59$).

A Mann-Whitney U test was conducted to evaluate difference between people with vestibular disorders and controls on the Body Mass Index (BMI), the Activities-specific Balance Confidence (ABC) Scale, and Functional Gait Assessment (FGA). The ABC, BMI and FGA were not statistically different between the groups.

6.3.2 Postural sway

The normality of postural sway measures scores was assessed by Shapiro-Wilk's test ($p > .05$) and the assumption of normality was not rejected. Despite the presence of some outliers, as assessed by inspection of a boxplot, the outliers were examined individually and kept in the analysis because they seemed to represent actual values of human sway. The mean (SD) of the dependent variables for each of the fixed effects appears in Table 6-6.

Table 6-6: Mean (SD) scores of the dependent variables in each level of the independent variables

	Level	RMS of pitch displacement (degree)		RMS of roll displacement (degree)		RMS of pitch velocity (deg/sec)		RMS of roll velocity (deg/sec)		RMS of AP acceleration (m/sec^2)		RMS of ML acceleration (m/sec^2)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Groups	P	0.62	0.38	0.39	0.31	1.03	0.73	0.92	0.80	0.12	0.07	0.09	0.06
	C	0.60	0.31	0.36	0.26	0.93	0.57	0.88	0.76	0.11	0.06	0.09	0.06
Surface	Firm	0.47	0.22	0.29	0.21	0.77	0.47	0.72	0.61	0.09	0.04	0.07	0.05
	Foam	0.76	0.38	0.46	0.32	1.19	0.70	1.09	0.88	0.15	0.07	0.11	0.07
Vision	EO	0.56	0.27	0.36	0.27	0.90	0.59	0.85	0.76	0.11	0.05	0.09	0.06
	EC	0.66	0.39	0.38	0.29	1.04	0.65	0.94	0.78	0.13	0.07	0.10	0.06
Stance	FA	0.55	0.29	0.22	0.12	0.79	0.48	0.67	0.59	0.11	0.06	0.06	0.04
	ST	0.67	0.37	0.54	0.30	1.17	0.71	1.15	0.87	0.13	0.06	0.12	0.06
Head	HS	0.57	0.35	0.34	0.28	0.77	0.60	0.57	0.63	0.10	0.06	0.07	0.06
	Yaw	0.66	0.32	0.40	0.27	1.19	0.57	1.27	0.75	0.13	0.06	0.11	0.06

P: patients; C: controls; RMS: Root Mean Square; Deg: degree; EO: eyes open; EC: eyes closed; FA: feet apart; ST: semi-tandem; HS: head still.

Results of the linear mixed model showed that the main effect of group was not statistically different on all quantitative postural measures. The main effects of surface condition, visual input, stance condition, and head movement were statistically significant at the 0.05 significance level on all quantitative postural measures such that standing on foam, eyes closed, semi-tandem stance, or yaw head movement produced higher sway than standing on firm surface, eyes open, feet apart, or head still respectively (Figures 6-3, 6-4, 6-5, and 6-6).

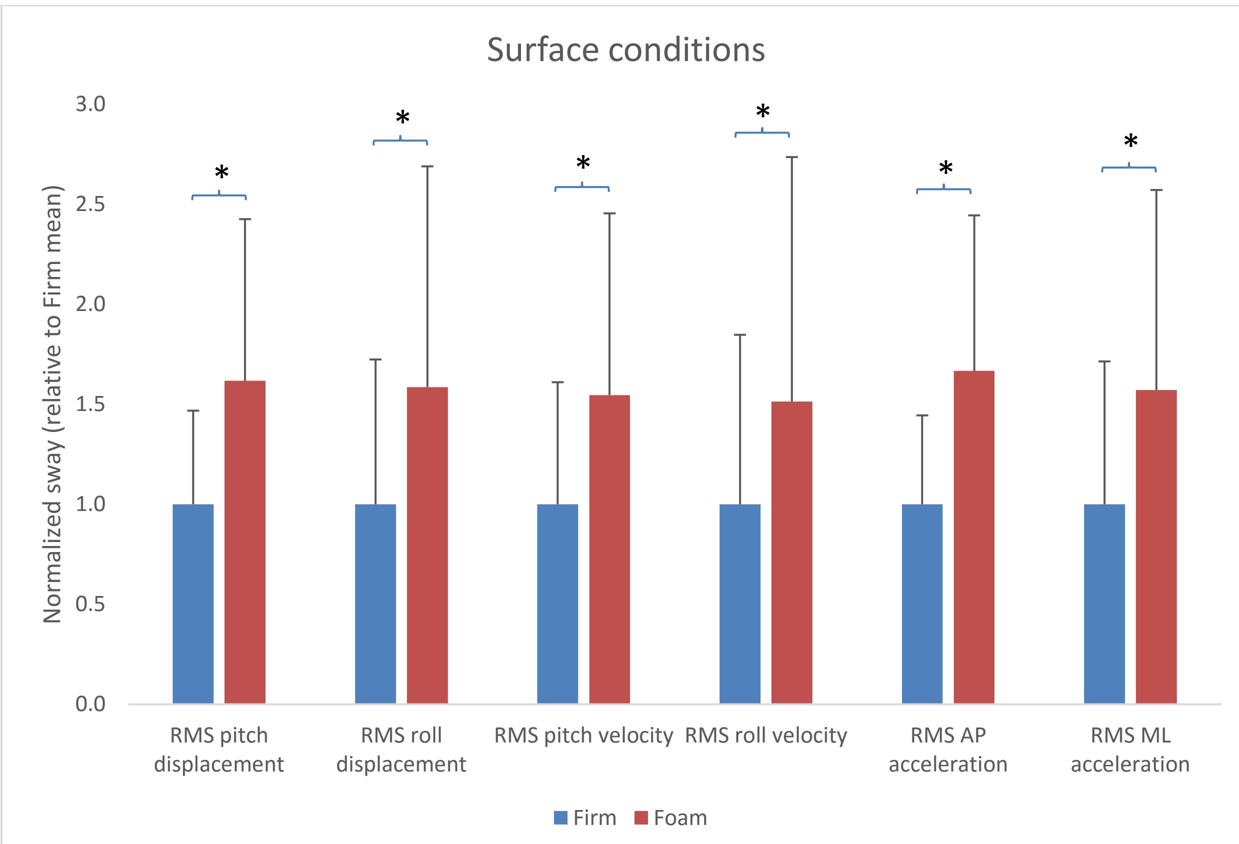


Figure 6-3: Mean scores of RMS trunk displacement, velocity, acceleration in pitch and roll directions during firm and foam conditions. Error bars represent population standard deviation. * p < 0.05 difference between pairs.

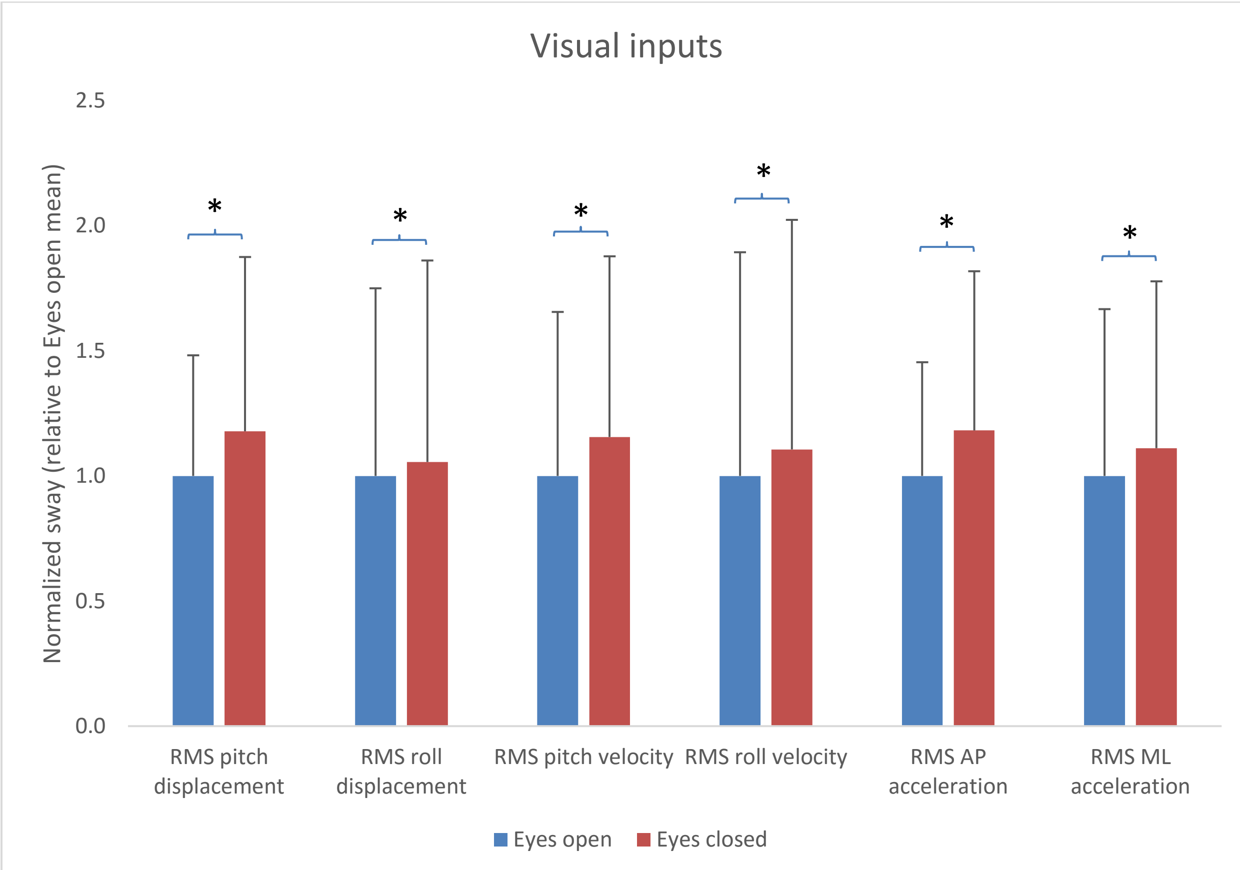


Figure 6-4: Mean scores of RMS trunk displacement, velocity, acceleration in pitch and roll directions during eyes open and eyes closed conditions. Error bars represent population standard deviation. * p < 0.05 difference between pairs.

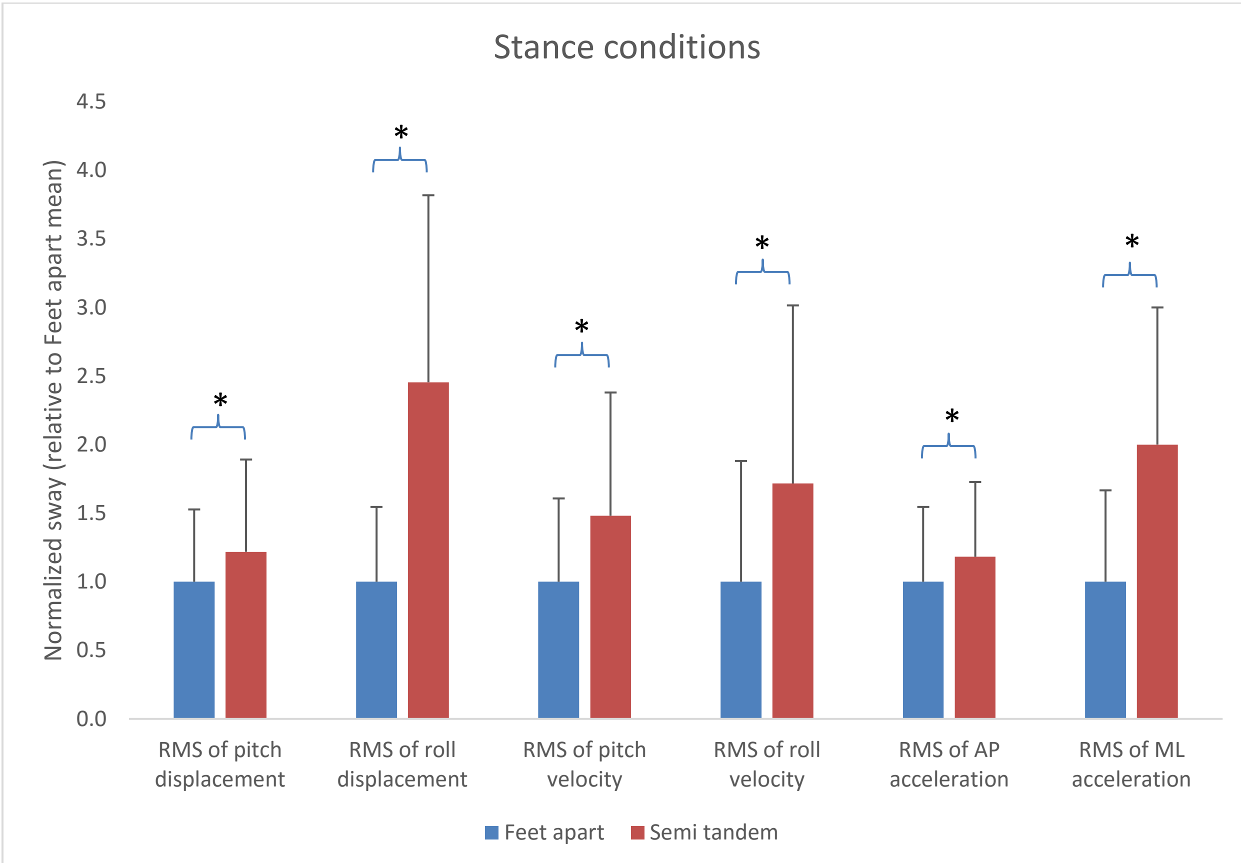


Figure 6-5: Mean scores of RMS trunk displacement, velocity, acceleration in pitch and roll directions during feet apart and semi tandem stance conditions. Error bars represent population standard deviation. * p < 0.05 difference between pairs.

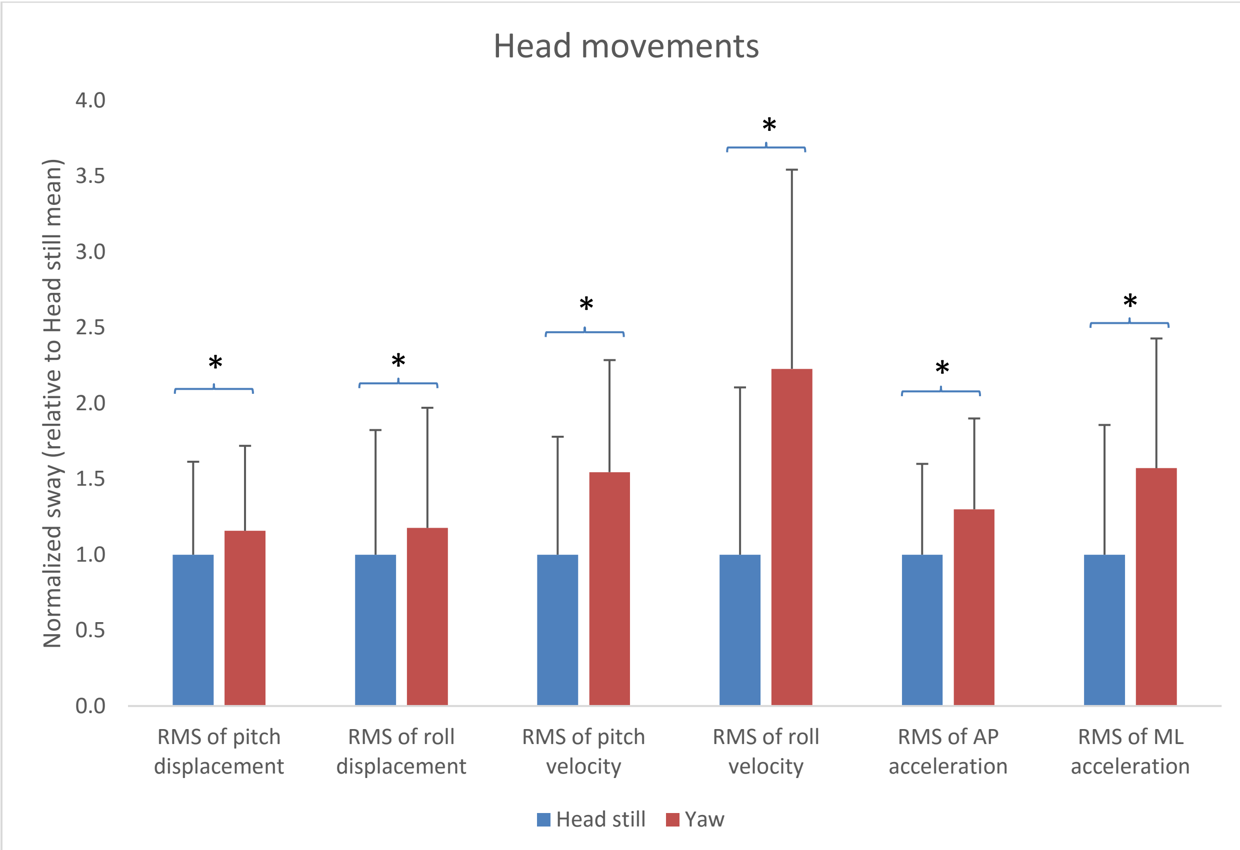


Figure 6-6: Mean scores of RMS trunk displacement, velocity, acceleration in pitch and roll directions during head still and yaw movements. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

The linear mixed model was used to explore two-way interaction effects between group and exercise conditions (surfaces, visual inputs, stances, and head movements) on quantitative postural measures (RMS of trunk angular displacement and velocity in the pitch and roll directions, and trunk linear acceleration in the AP and ML acceleration). There was a significant interaction between group and stance type in three of the sway measures (RMS of trunk angular displacement in roll direction and velocity in the pitch direction, and trunk linear acceleration in the ML direction), and between group and head movement in three of the sway measures (RMS of trunk angular velocity in the pitch and roll directions, and trunk linear acceleration in the ML direction). Conversely, there was no significant interaction between group and surface type or visual input in all sway measures. The RMS pitch velocity will be used to illustrate these interactions.

There was a significant interaction between group and stance type in which the difference between feet apart and semi-tandem increased more in the people with vestibular disorders group compared with controls (Figure 6-7). Similarly, people with vestibular disorders had greater sway during head still but there was not a difference between groups during moving head in the yaw direction (Figure 6-8).

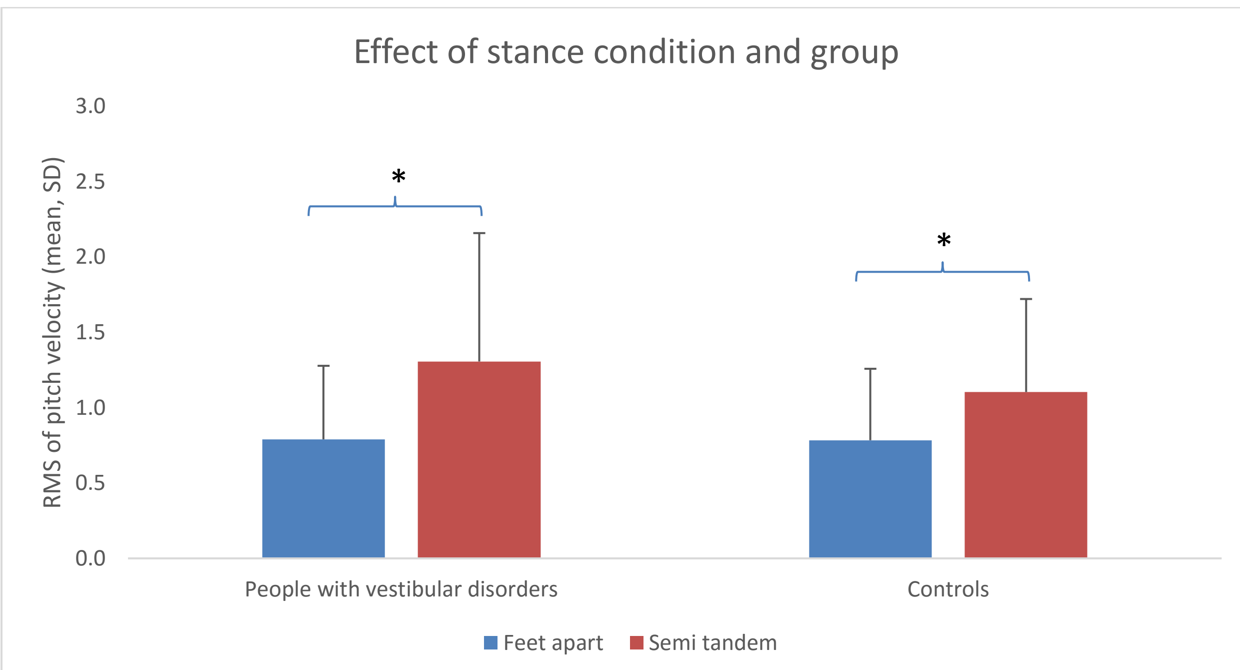


Figure 6-7: Interaction effect between stance condition and groups in the RMS of pitch velocity (mean, SD). * p < 0.05 difference between pairs.

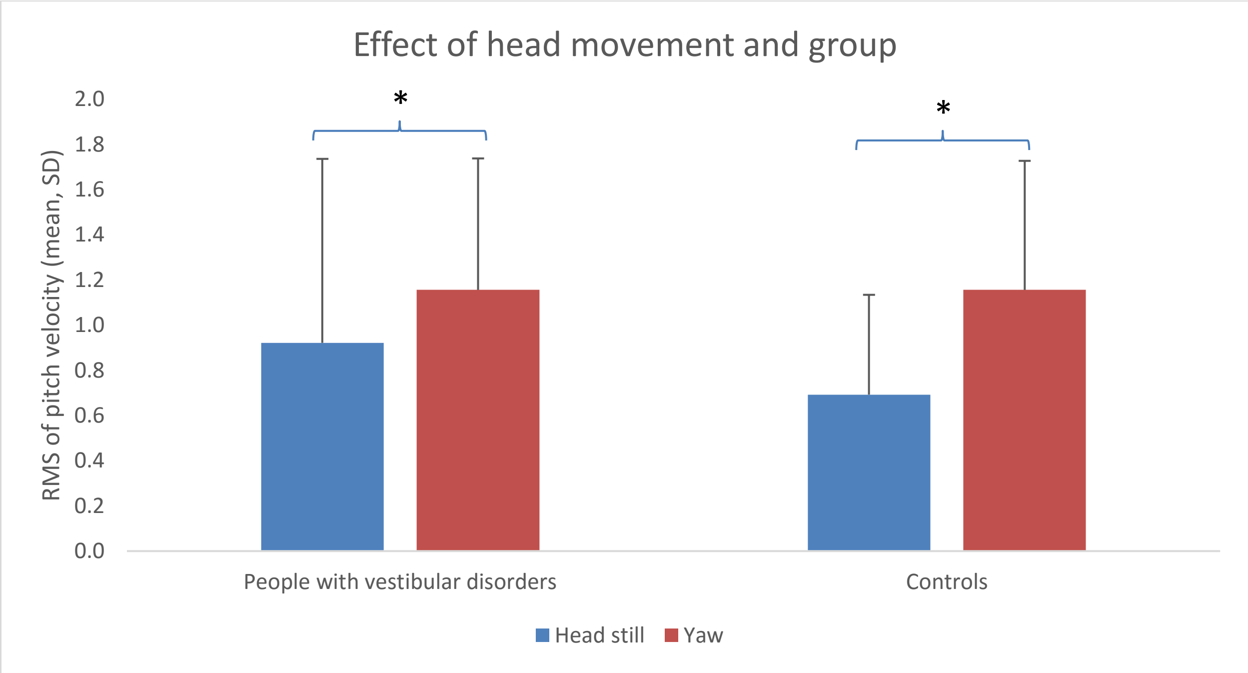


Figure 6-8: Interaction effect between head movements and groups in the RMS of pitch velocity (mean, SD). * *p* < 0.05 difference between pairs.

6.3.3 Ratings of perceived difficulty

The mean scores of the ratings of perceived difficulty scales A and B for groups, surface types, visual input, stance condition, and head movement are displayed in Table 6-6. The results of Mann-Whitney U test demonstrated a significant difference between the different levels of groups on Scale A (U = 31.0, p = 0.04). People with vestibular disorders rated the difficulty of exercises nearly one point higher than control subjects. The mean scores of rating of perceived difficulty of Scale B were not significantly different between the two groups (U = 43.5, p = 0.21) (Figure 6-9).

The results of Wilcoxon signed-rank test showed a significant difference between the type of surface (Z = -4.29, p <0.001) (Z = -4.29, p <0.001), type of visual input (Z = -4.24, p <0.001) (Z = -4.15, p <0.001), type of stance (Z = -4.29, p <0.001) (Z = -4.29, p <0.001), and head movement (Z = -4.29, p <0.001) (Z = -4.29, p <0.001) on the rating of perceived difficulty Scales A and B respectively, with increased ratings on foam compared with firm, eyes closed versus eyes open, semi-tandem stance related to feet apart, and head still compared with yaw head movement (Figures 6-10, 6-11, 6-12, and 6-13).

Table 6-7: Mean scores and standard deviations of Scales A and B in each level of the independent variables

Independent variables	Level	Scale A (0-10)		Scale B (1-5)	
		Mean	SD	Mean	SD
Group	People with vestibular disorders	3.80	1.10	2.20	0.45
	Controls	2.86	0.98	1.93	0.41
Surface	Firm	1.98	1.00	1.54	0.34
	Foam	4.36	1.28	2.49	0.56
Vision	Eyes open	2.68	1.01	1.83	0.43
	Eyes closed	3.67	1.24	2.21	0.47
Stance	Feet apart	1.65	0.98	1.45	0.39
	Semi-tandem	4.70	1.40	2.59	0.52
Head	Head still	2.36	0.87	1.72	0.36
	Yaw	3.98	1.41	2.32	0.54

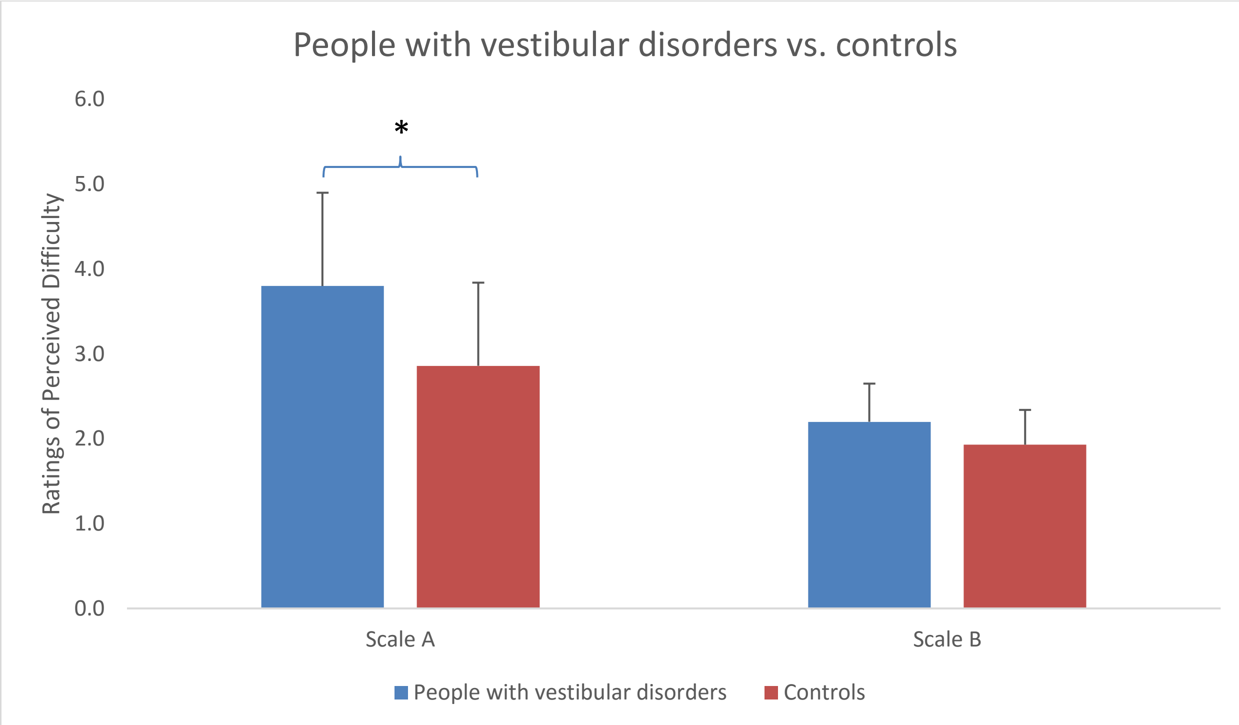


Figure 6-9: Differences among the groups (people with vestibular disorders and controls) on mean of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * p < 0.05 difference between pairs.

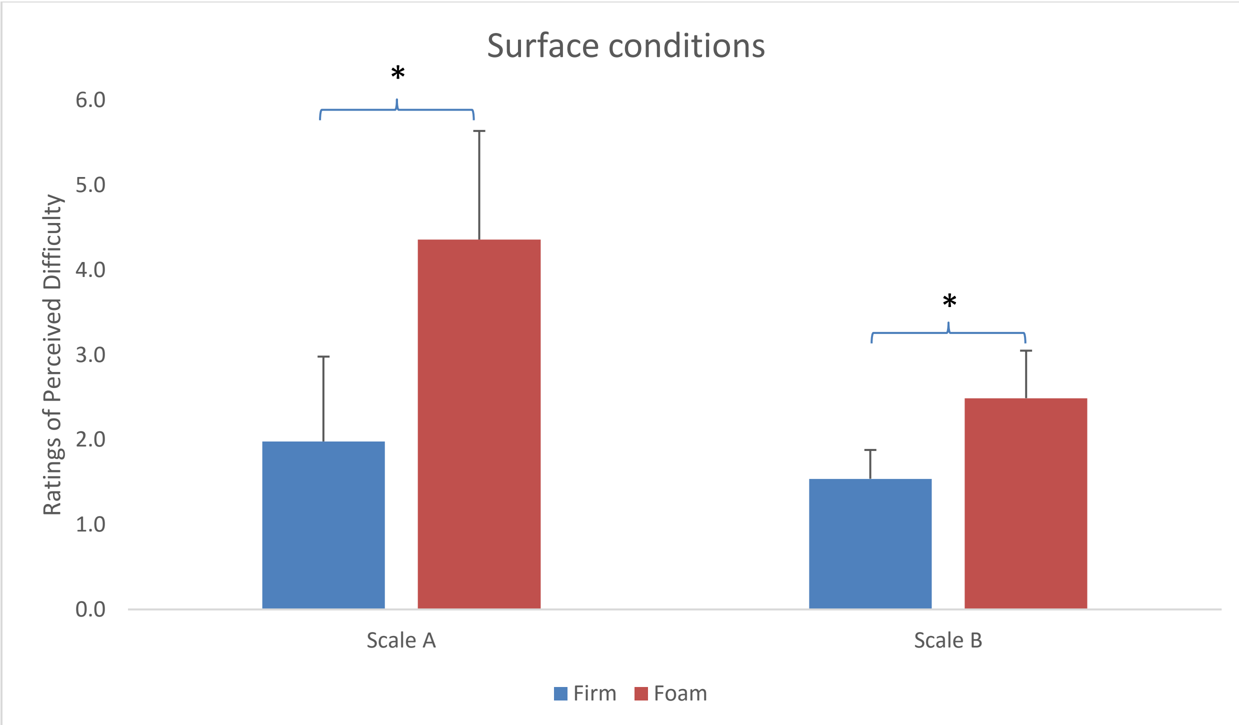


Figure 6-10: Differences between the two types of surface (firm and foam surfaces) on mean of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

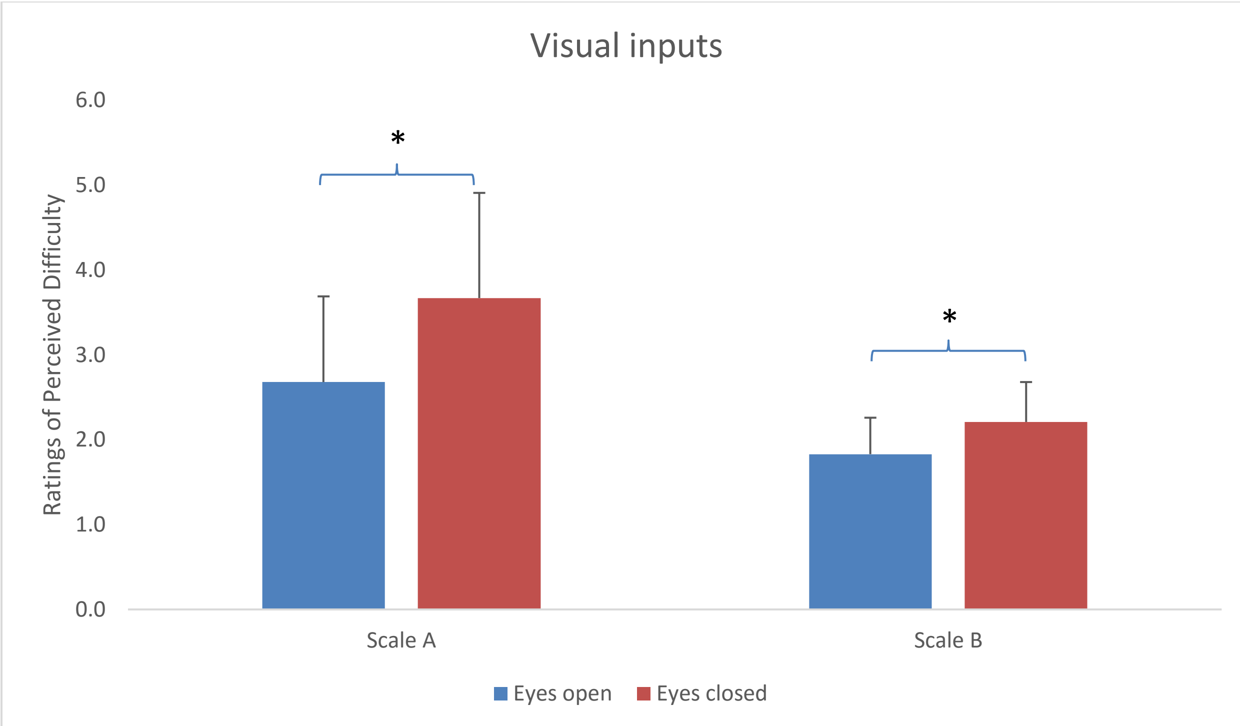


Figure 6-11: Differences between the two types of visual input (eyes open and eyes closed) on mean of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

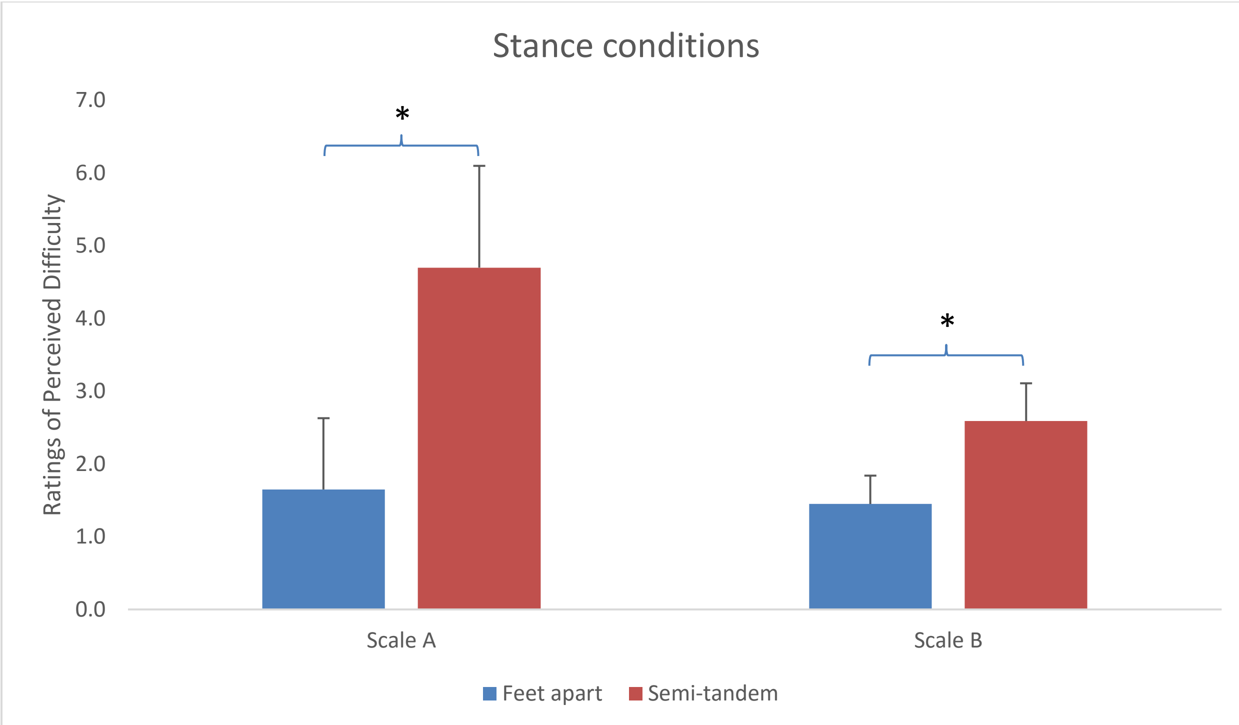


Figure 6-12: Differences between the two types of stance (feet apart and semi-tandem) on mean of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * $p < 0.05$ difference between pairs.

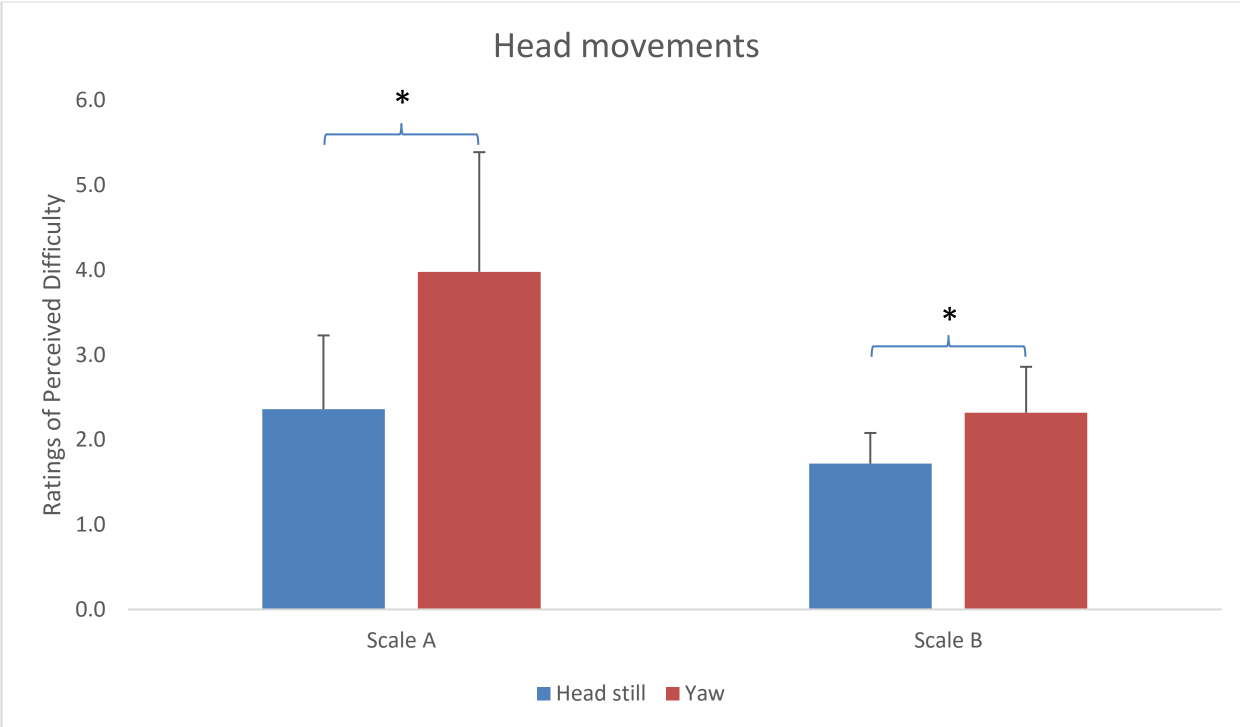


Figure 6-13: Differences among the head movements (head still and yaw) on mean of rating of perceived difficulty Scale A and B. Error bars represent population standard deviation. * p < 0.05 difference between pairs.

6.4 DISCUSSION

The purpose of this study was to determine the effect of vestibular disorders on postural and perceptual measures of balance. The participants in this study had peripheral vestibular disorders. On average, they demonstrated a good level of function, similar to what has been reported by other studies about general populations of community-dwelling adults' gait speed (Abellan van Kan et al., 2009; Bohannon, 1997; Michelle M. Lusardi, 2003; Victoria Hornyak, 2012), Functional Gait Assessment (FGA) (Walker et al., 2007; Wrisley & Kumar, 2010), and Activities-specific Balance Confidence (ABC) scale (Huang & Wang, 2009; Myers et al., 1998). Compared to healthy controls who were included in this study and were age and gender matched, people with vestibular disorders were not different in gait speed, FGA, and ABC. Compared with other vestibular disorders populations, people with vestibular disorders in this study had similar average gait speed to what has been reported by Hall and Herdman (Hall & Herdman, 2006), higher median FGA scores compared with what Wrisley et al. reported in their study (Wrisley et al., 2004), and a better median ABC score than what was reported in Marchetti et al.'s study of 95 people with signs and symptoms of vestibular dysfunction (Marchetti, Whitney, Redfern, & Furman, 2011).

Although vestibular disorders have been reported to contribute to increasing postural instability (Baloh et al., 1998; Fujimoto et al., 2014), the results of this study did not show a difference between people with vestibular disorders and healthy matched subjects on any of the postural sway measures. The findings of our study seem to be consistent with Baloh et al.'s work when using similar exercise conditions (standing on firm surface with eyes closed or on foam surface with eyes open or closed) (Baloh et al., 1998). However, in a comparison of the postural sway between 70 patients with peripheral and central vestibular disorders or reported dizziness and imbalance for an unknown reason, and 70 control subjects, all over the age of 75, sway velocity was significantly higher in patients than controls while standing on a platform that was tilting (Baloh et al., 1998). Another study compared 58 patients with vestibular neuritis between 23 – 83 yrs. and 66 healthy matched subjects and found an increase in postural sway in patients during standing on foam with eyes closed (Fujimoto et al., 2014).

The contradictory results between our study and other studies might be because the people with vestibular disorders in this study were very functional compared with similar populations recruited in other studies. Various studies have shown that people with vestibular disorders during the acute stage exhibit postural instability but eventually recover normal postural control as an indication of central compensation (Black, Shupert, Peterka, & Nashner, 1989; Parietti-Winkler, Gauchard, Simon, & Perrin, 2010). Another reason for this conflict could be due to the use of different exercise conditions, including many exercises of varying difficulties, which could have resulted in increased variance, making it more difficult to find between group differences. Additional analysis was done in this study to compare between people with vestibular disorders and controls on the amount of postural sway for each individual exercise. The results did not show any difference between the groups in any of the postural sway measures. Moreover, other studies that reported a difference between patients and healthy matched subjects may have included participants with different vestibular disorders. Various vestibular disorder diagnoses may affect postural control differently (Baloh et al., 1998; Hong et al., 2013). Hong et al. found that people who have vestibular neuritis have more sway during conditions 5 (standing with eyes closed on sway-referenced platform surface) and 6 (standing with eyes open on sway-referenced platform surface and with a sway-referenced visual background) of the SOT compared with individuals who have Meniere’s disease or migrainous vertigo. Whereas in condition 2 (standing with eyes closed on fixed platform), people with migrainous vertigo swayed significantly more than those who had vestibular neuritis (Hong et al., 2013). Individuals with vestibular disorders such as bilateral vestibular loss and cerebellar atrophy tend to have higher sway velocity during static or dynamic standing with eyes closed compared with individuals with unilateral vestibular loss, central disorders, or those having dizziness and imbalance of unknown cause (Baloh et al., 1998). Furthermore, the small sample size of people with vestibular disorders may have decreased the power of finding a statistically significant difference between patients and healthy matched subjects.

On the contrary, the rating of perceived difficulty scores from Scale A were different between people with vestibular disorders and control subjects, although the sway measures and the rating of perceived difficulty of Scale B were not significantly different between the groups. The discrepancy between the sway parameters and the ratings of perceived difficulty in Scale A demonstrating differences between the groups may indicate that individuals with vestibular disorders are considering other factors besides their sway to rate perceived difficulty. These factors may include strain, discomfort and/or fatigue, and negative emotional factors that are experienced during performance of balance exercises (Borg, 1982; Noble & Robertson, 1996). Scale A has more variability in regards to the rating levels (11 levels) compared with Scale B (5 levels) which may explain why Scale A differentiated between people with vestibular disorders and controls. The capability of Scale A to find a difference between patients and healthy subjects is considered an advantage for Scale A over Scale B and sway parameters that were used in this study. It suggests the importance of using Scale A in studies aiming to explore the effect of vestibular disorders on postural control or in balance training programs aiming to assess the challenge level of balance exercises.

In additional analysis that looked at differences between people with vestibular disorders and controls on the rating of perceived difficulty scores of Scales A and B for each individual exercise, we found differences between the groups for exercises 5, 8, 10, and 11 for Scale A, and exercises 8 and 11 for Scale B. It was noted that all the exercises that have been able to create a difference in the ratings of perceived difficulty between the groups were during standing on firm surface and three of the four exercises were either with eyes closed, semi-tandem, or/and head movement from side to side.

The results confirmed the hypothesis that the exercise conditions (surface type, visual input, stance condition, and head movement) would increase sway measures and rating of perceived difficulty. The present findings are consistent with other research which found an increase in body sway with alteration of sensory information through decreasing proprioceptive information by standing on foam (Abrahamova & Hlavacka, 2008; Cohen et al., 1996; Gill et al., 2001), lack of visual information by closing eyes (Abrahamova & Hlavacka, 2008; Cohen et al., 1996; Era et al., 2006; Gill et al., 2001; Hytonen et al., 1993), and narrowing the base of support by standing in semi-tandem stance (Era et al., 2006). In addition, the ratings of Scale A and B were higher when decreasing proprioception information by standing on foam, lack of visual information by closing eyes, narrowing base of support by standing in semi-tandem stance, and altering vestibular function through head movements, which is consistent with the results of the sway measures analysis.

With regards to the interaction between groups and exercise conditions, there was no interaction effect between surface or visual conditions and group levels. By contrast, there was a interaction effect between group levels and stance conditions and head movements on quantitative postural measures. The vestibular disorders group had greater increases in sway compared with the healthy group as the condition become more difficult with narrowing the base of support. A study that included older adult controls and subjects who reported imbalance showed increased postural sway in both groups during conditions with eyes closed, standing on foam, or a tilting platform (Baloh et al., 1998). Similar to our current findings, when the challenge of the postural task increased (by tilting the platform sinusoidally), the RMS sway velocity increased by a greater amount in the older adults with dizziness and imbalance compared with older controls. (Baloh et al., 1998). Thus the principle of vestibular rehabilitation to increase the difficulty of balance exercises appears to be well-founded, given that these impairments in balance appear with the more difficult exercises.

The other significant interaction that was observed was the head movement by group interaction. In this case, healthy subjects had greater increases in sway velocity compared with people with vestibular disorders when changing from head still to moving head side-to-side. The larger change in sway in the control group resulted because the controls had a lower sway velocity magnitude in the head still conditions compared with the vestibular group, while both groups had nearly the same amount of sway in the yaw movement conditions. These results are somewhat surprising given the head still conditions were relatively easy, where we would not expect a difference between groups. Alternatively, we would have expected more of a difference between groups in the head yaw condition, given the compromised status of the vestibular system in the vestibular group. However, this finding may reflect how well the individuals with vestibular disorders had compensated.

6.5 LIMITATIONS

The study visit required one hour and forty-five minutes and even longer for older adults, which may have caused fatigue. However, randomizing the testing conditions for each subject and providing rest breaks every three exercises may have eliminated the fatigue effect.

Although subjects practiced the head movement in the yaw direction with a laser light attached to the head before they started the experiment, the laser light was not used during the experiment and subjects may not have had a good control over the range of head movement during exercises with yaw head movement. Due to this limitation, subjects may have decreased the range or the speed of head movement in order to maintain their balance.

The small sample size of people with vestibular disorders may have decreased the power of finding a statistically significant difference between patients and healthy matched subjects. However, given the effect size of 0.15 obtained from these results, it would have taken 245 subjects in the vestibular group in order to detect a difference.

6.6 CONCLUSION

Postural sway measures and ratings of perceived difficulty were able to demonstrate surface, vision, stance, head movement effects. However, individuals with vestibular disorders did not produce more sway compared with controls, but they did have higher ratings of perceived difficulty with Scale A, which may consider advantageous over Scale B, and sway parameters.

7.0 GENERAL DISCUSSION

This primary motivation of this study was to address the lack of valid measures to quantify the intensity of balance exercise difficulty (Farlie et al., 2013; Pescatello & American College of Sports Medicine., 2014). This research is intended for physical therapists and other clinicians who provide balance interventions, in order to help them to accurately prescribe balance and vestibular exercises to their clients. In this study, we intended to establish the reliability and validity of two new developed rating of perceived difficulty scales in order to use them to quantify the difficulty of balance exercises in cases where postural sway measurement is not possible. In addition, we investigated the effect of age, vestibular disorders, and exercise conditions on postural and perceptual measurements.

The first aim of this study was to examine the test-retest reliability of subjects' performance during standing balance exercises. The reason for undertaking this aim was that, although test-retest reliability of postural sway measures of subjects' performance during the static standing balance exercises had been investigated in previous studies (Benvenuti et al., 1999; Doyle et al., 2007; Goldie et al., 1989; Heebner et al., 2015; Hertel et al., 2006; Lafond et al., 2004; Moe-Nilssen, 1998; Rafal et al., 2011; Ruhe et al., 2010; Swanenburg et al., 2008), it had been limited to a fewer number of exercises. Additionally, to our knowledge, the reliability of ratings of perceived difficulty of static standing balance exercises has never been investigated. As a result, we examined the test-retest reliability of postural sway measures of subjects' performance and perceptual ratings of the difficulty of static standing balance exercises by measuring sway performance using an IMU and perceptual ratings using two rating of perceived difficulty scales, during 24 different balance exercises that were conducted two times each on two visits occurring one week apart. We found that all of the quantitative sway measures that we examined demonstrated acceptable reliability, while sway velocity measures were the most reliable. Furthermore, after averaging two trials from each visit, the reliability coefficients increased significantly for all sway measures to be moderate to excellent, which indicates clearly the importance of averaging two trials in order to obtain reliable measures. Rating of perceived difficulty Scales A and B demonstrated fair to substantial agreement with few exceptions. Therefore, the results suggest that sway measures and ratings of perceived difficulty have sufficient reliability to be used as measures of balance exercise intensity.

Currently, there are no established methods for quantifying the intensity of balance exercises (Farlie et al., 2016; Farlie et al., 2013; Pescatello & American College of Sports Medicine., 2014), which presents a barrier for being able to prescribe the initial intensity and progress the intensity of balance exercises. In many settings such as balance rehabilitation clinics, advanced tools such as force platforms or accelerometers are not in common use to quantify balance intensity and performance. Therefore, it would be useful to employ another measure to serve this purpose. In other rehabilitation settings, ratings of perceived exertion are commonly used to monitor relative intensity of aerobic or resistance exercises (Pescatello & American College of Sports Medicine., 2014; Robertson et al., 2004; Robertson et al., 2003; Utter et al., 2004). Therefore, we wanted to see if a similar rating method could be developed for balance exercise. The second aim of the study was to validate two scales of ratings of perceived difficulty of balance exercises by comparing the rating scales with quantitative sway measures, using a linear regression based analysis. We compared the scores from the rating scales that we developed in this study with quantitative sway measures because sway measures were commonly used in the balance literature to describe the postural stability. The ratings of perceived difficulty scales had moderate to strong correlations with quantitative postural measures, demonstrating concurrent validity. Based on the findings of the reliability and validity studies, either of the two scales (Scale A and B) of rating of perceived difficulty of balance exercises can be used in clinic to establish a scientific basis for quantifying balance exercise difficulty. However, other factors may make the decision to use one or the other scales a better choice, as discussed below.

The purposes of the third and fourth aims were to determine the relative difficulty of a wide variety of static standing exercises commonly performed in balance and vestibular rehabilitation, and validate common rubrics for treatment progression by recording postural sway measures (trunk tilt) and perceived difficulty. In addition, we desired to determine the effect of age on postural and perceptual measures over a wide spectrum of ages from 18 to 85 years old, as well as to understand the effect of having vestibular disorders on postural sway measures and the perceived difficulty. For the third aim, participants performed 24 randomized static standing balance exercises, which were a full-factorial design of the following different conditions: vision (eyes open and eyes closed); surface (firm and foam); base of support (feet apart and semi-tandem); and head movements (head still, yaw, and pitch). For the fourth aim, subjects with vestibular disorders and matched healthy subjects were asked to perform two sets of 16 randomized static standing exercises, which were a full-factorial design of the following different conditions: vision (eyes open and eyes closed); surface (firm and foam); base of support (feet apart and semi-tandem); head movements (head still and yaw). During the performance of each exercise, sway was measured and participants rated the perceived difficulty of each exercise. Postural sway measures and ratings of perceived difficulty were able to demonstrate age, surface, vision, stance, and head movement effects. However, only the rating of perceived difficulty Scale A was able to show a difference between people with vestibular disorders and control subjects, which is considered an advantage for Scale A over Scale B and sway parameters. The lack of finding a difference between people with vestibular disorders and healthy matched subjects on any of the postural sway measures may be attributed to the good functional level compared with similar populations recruited in other studies that may indicate that they had good central compensation after their vestibular injury. Additionally, the small sample size of people with vestibular disorders may have decreased the power of finding a statistically significant difference between patients and healthy matched subjects.

At the end of this study, clinicians can use the rating of perceived difficulty scales to estimate the intensity of each exercise in situations when sway cannot be measured. During training programs, rating of perceived difficulty scales can help to monitor the intensity of the exercises and provide clinicians with feedback of how challenging the exercises are to their clients, as well as feedback about if their clients are ready to progress to the next level of intensity. Additionally, ratings of perceived difficulty can be used for home-based balance exercise training so that the client can monitor if the home exercises are meeting the prescribed intensity targets. The sway measures collected could be used to set ranges of normal limits of sway for different age groups, and can be used as reference of normative data when comparing patients' data to others. Finally, the 90% range and IQR values could be used for augmented sensory feedback devices to set the threshold limits of when feedback should be activated.

The findings of this study may be generalized to other type of balance exercise categories such as dynamic balance exercises, as they share most of the measurements and exercise conditions with static standing balance exercises. However, it is probably more difficult to generalize the findings of this study to other exercise categories, such as walking exercises, because the measurements that are used to quantify balance during walking are different from static standing balance exercises. In addition, the strategies used to maintain balance during walking are different than during static standing.

7.1 LIMITATIONS

Each study visit required one hour and forty-five minutes and even longer for older adults which may have caused fatigue (Helbostad et al., 2010; Nardone, Tarantola, Giordano, & Schieppati, 1997). However, randomizing the testing conditions during the experiment sessions and visits for each subject and the rest breaks every three exercises could eliminate the fatigue effect.

During data collection of the ratings of perceived difficulty, ratings may not have been completely independent. The participants rated the difficulty of the same exercises twice during the first visit, and twice during the second visit. As a result, participants may have recalled their first rating when making their second rating. This dependency in ratings recall may inflate the kappa coefficients. However, due to the large number of exercises included in our study, and the randomization of the trials, it would have been difficult for participants to recall previous ratings.

Although subjects practiced the head movement in yaw and pitch directions with a laser light attached to the head before they started the experiment, the laser light wasn't used during the experiment and subjects may not have had a good control over the range of head movement during exercises with yaw and pitch head movements. Due to this limitation, subjects may have decreased the range or the speed of head movement in order to maintain their balance.

The results of this study did not show a difference between people with vestibular disorders and controls subjects on any of the postural sway measures. The lack of a difference between patients and controls might be due to the small sample size of people with vestibular disorders, which may have decreased the power of finding a statistically significant difference between patients and healthy matched subjects. Another reason may explain the lack of a difference between the groups is that people with vestibular disorders in this study were believed to have good compensation after their injury based on their ABC and FGA scores, which were within normal levels. Future studies may include a larger sample size of people with vestibular disorders and may include variety of diagnoses of vestibular disorders to see whether different vestibular diagnoses affect postural sway measures and ratings of perceived difficulty differently.

Due to undetected problems with the force platform that consisted of failure of multiple load cells, a loss of a high percentage of data (27% in middle-aged group, 20% in older adult group, and 13% in very old group), the COP data were excluded from the final statistical analysis to test the hypotheses. As a result, we were not able to compare between measures from the force plate and IMU.

8.0 FUTURE WORK

Future studies may investigate which balance strategies or components (e.g. muscle activity, ankle/hip strategies, or reaching functional stability limits) used to maintain balance, are driving the rating of perceived difficulty. In addition, personality traits and functionality status such as overall body strength, gait speed, Functional Gait Assessment (FGA) may be examined to see their effects on postural and perceived measurements of performance of balance exercises.

In this study, we established the reliability and validity of the rating of perceived difficulty scales A and B in static standing balance exercises for healthy adults. Future studies may investigate the responsiveness of these scales in a clinical setting. Furthermore, psychometric properties may be investigated in different age or diagnosis populations as well as different types of balance exercises such as dynamic standing and walking exercises.

9.0 CONCLUSION

The purpose of this study was to establish the reliability and validity of two developed rating of perceived difficulty scales in order to use them to quantify the difficulty of balance exercises in cases where postural sway measurement is not possible. In addition, we investigated the effect of age, vestibular disorders, and exercise conditions on postural and perceptual measurements.

The results demonstrated that the subjects' performance and their rating of perceived difficulty of standing balance exercises are reliable. The RMS of trunk tilt velocity in the roll direction was the most reliable measure on average. The reliability scores of the sway measures increased after averaging two trials, which indicates clearly the importance of averaging 2 trials in order to obtain reliable measures. The ratings of perceived difficulty scales had moderate to strong correlations with quantitative postural measures, demonstrating concurrent validity.

For the third aim, postural sway measures and ratings of perceived difficulty were able to demonstrate age, surface, vision, stance, head movement effects. Quantitative sway measures and ratings of perceived difficulty can be used to prescribe intensity of balance exercises and guide progression during rehabilitation. In this study, we developed a sequence of 24 static standing balance exercises from the exercise that produced the least amount of sway and rating to the exercise that generated the highest sway and rating of perceived difficulty, which can be used in balance rehabilitation programs.

For the fourth aim, postural sway measures and ratings of perceived difficulty were able to demonstrate surface, vision, stance, head movement effects. However, Individuals with vestibular disorders did not produce more sway compared with controls, but they did have higher ratings of perceived difficulty Scale A, which is considered an advantage for Scale A over Scale B, and sway parameters.

APPENDIX A

Intraclass correlation coefficients, model (3, 1) of sway measures within and between visits

Intraclass correlation coefficients, model (3, 1) of sway measures within the 1st visit

Exercise	RMS of pitch displacement	RMS of roll displacement	RMS of pitch velocity	RMS of roll velocity	RMS of AP acceleration	RMS of ML acceleration
1	0.17	0.27	0.71	0.79	0.28	0.44
2	0.29	0.67	0.62	0.80	0.32	0.71
3	0.42	0.11	0.59	0.80	0.56	0.40
4	0.42	0.67	0.67	0.70	0.60	0.73
5	0.51	0.69	0.63	0.67	0.58	0.71
6	0.44	0.50	0.47	0.53	0.64	0.59
7	0.38	0.47	0.56	0.81	0.45	0.71
8	0.44	0.67	0.64	0.53	0.56	0.59
9	0.36	0.49	0.63	0.68	0.48	0.58
10	0.21	0.17	0.59	0.35	0.26	0.37
11	0.33	0.43	0.45	0.55	0.34	0.49
12	0.37	0.49	0.51	0.59	0.49	0.49
13	0.42	0.45	0.73	0.63	0.53	0.57
14	0.56	0.73	0.61	0.63	0.63	0.69
15	0.54	0.56	0.48	0.67	0.57	0.58
16	0.38	0.70	0.75	0.70	0.48	0.73
17	0.52	0.63	0.57	0.61	0.52	0.54
18	0.61	0.65	0.67	0.66	0.62	0.58
19	0.49	0.63	0.87	0.66	0.60	0.62
20	0.19	0.44	0.32	0.78	0.23	0.63
21	0.41	0.45	0.51	0.51	0.42	0.45
22	0.66	0.43	0.70	0.47	0.67	0.53
23	0.12	0.66	0.18	0.71	0.34	0.68
24	-0.04	0.32	0.37	0.43	-0.05	0.28
Average score	0.38	0.51	0.58	0.64	0.46	0.57

Intraclass correlation coefficients, model (3, 1) of sway measures within the 2nd visit

Exercise	RMS of pitch displacement	RMS of roll displacement	RMS of pitch velocity	RMS of roll velocity	RMS of AP acceleration	RMS of ML acceleration
1	0.52	0.43	0.73	0.65	0.58	0.47
2	0.42	0.71	0.68	0.78	0.46	0.72
3	0.35	0.49	0.44	0.55	0.42	0.59
4	0.41	0.31	0.48	0.77	0.40	0.54
5	0.66	0.72	0.65	0.73	0.68	0.74
6	0.69	0.75	0.58	0.63	0.69	0.70
7	0.24	0.31	0.12	0.06	0.24	0.27
8	0.53	0.77	0.64	0.77	0.62	0.71
9	0.67	0.50	0.83	0.62	0.68	0.48
10	0.41	0.46	0.67	0.57	0.45	0.56
11	0.37	0.45	0.57	0.65	0.38	0.53
12	0.44	0.22	0.78	0.30	0.47	0.41
13	0.31	0.58	0.58	0.61	0.37	0.62
14	0.49	0.63	0.58	0.83	0.50	0.75
15	0.63	0.66	0.63	0.66	0.62	0.66
16	0.32	0.63	0.41	0.58	0.39	0.60
17	0.53	0.58	0.65	0.76	0.52	0.61
18	0.57	0.41	0.59	0.60	0.60	0.45
19	0.50	0.15	0.41	0.21	0.51	0.22
20	0.43	0.71	0.69	0.79	0.53	0.78
21	0.80	0.78	0.69	0.70	0.81	0.76
22	0.71	0.81	0.83	0.85	0.72	0.81
23	0.52	0.84	0.68	0.77	0.46	0.80
24	0.54	0.46	0.55	0.60	0.53	0.52
Average score	0.50	0.56	0.60	0.63	0.53	0.59

Intraclass correlation coefficients, model (3, 1) of sway measures between visits (1st session in 1st visit and 1st session in 2nd visit)

Exercise	RMS of pitch displacement	RMS of roll displacement	RMS of pitch velocity	RMS of roll velocity	RMS of AP acceleration	RMS of ML acceleration
1	0.47	0.43	0.58	0.52	0.53	0.50
2	0.07	0.59	0.62	0.63	0.24	0.60
3	0.39	0.28	0.38	0.41	0.32	0.47
4	0.33	0.25	0.54	0.31	0.37	0.38
5	0.34	0.81	0.48	0.71	0.37	0.71
6	0.42	0.14	0.35	0.31	0.41	0.37
7	0.45	0.21	0.41	0.19	0.51	0.18
8	0.44	0.54	0.58	0.34	0.56	0.50
9	0.43	0.46	0.47	0.51	0.41	0.47
10	0.08	0.19	0.72	0.39	0.15	0.38
11	0.44	0.48	0.62	0.50	0.45	0.56
12	0.37	0.33	0.55	0.51	0.44	0.45
13	0.38	0.48	0.52	0.57	0.43	0.61
14	0.53	0.61	0.55	0.65	0.59	0.66
15	0.43	0.49	0.26	0.47	0.45	0.53
16	0.47	0.50	0.41	0.50	0.50	0.54
17	0.44	0.58	0.42	0.59	0.41	0.56
18	0.41	0.51	0.51	0.69	0.37	0.51
19	0.61	0.34	0.51	0.24	0.66	0.36
20	0.46	0.56	0.46	0.42	0.42	0.64
21	0.59	0.57	0.38	0.38	0.51	0.55
22	0.37	0.43	0.39	0.36	0.39	0.44
23	0.44	0.61	0.45	0.58	0.20	0.55
24	0.07	0.24	0.01	0.55	-0.04	0.31
Average score	0.39	0.44	0.47	0.47	0.40	0.49

Intraclass correlation coefficients, model (3, 1) of sway measures between visits (2nd session in 1st visit and 2nd session in 2nd visit)

Exercise	RMS of pitch displacement	RMS of roll displacement	RMS of pitch velocity	RMS of roll velocity	RMS of AP acceleration	RMS of ML acceleration
1	0.42	0.45	0.62	0.64	0.45	0.54
2	0.44	0.60	0.68	0.65	0.34	0.58
3	0.21	0.26	0.49	0.78	0.07	0.45
4	0.20	0.52	0.29	0.63	0.17	0.68
5	0.54	0.67	0.61	0.64	0.53	0.67
6	0.58	0.48	0.60	0.59	0.48	0.61
7	0.19	0.11	0.10	0.10	0.19	0.11
8	0.58	0.57	0.75	0.57	0.62	0.64
9	0.46	0.39	0.68	0.69	0.46	0.60
10	0.28	0.14	0.53	0.40	0.32	0.33
11	0.19	0.43	0.56	0.57	0.21	0.46
12	0.33	0.30	0.62	0.42	0.36	0.41
13	0.35	0.55	0.66	0.58	0.31	0.59
14	0.63	0.69	0.72	0.70	0.63	0.71
15	0.63	0.63	0.52	0.60	0.61	0.65
16	0.30	0.36	0.06	0.17	0.38	0.35
17	0.31	0.43	0.51	0.36	0.31	0.38
18	0.55	0.59	0.48	0.65	0.54	0.55
19	0.43	0.53	0.76	0.64	0.49	0.60
20	0.43	0.63	0.67	0.56	0.46	0.66
21	0.55	0.60	0.63	0.58	0.58	0.65
22	0.36	0.41	0.31	0.34	0.37	0.46
23	0.51	0.76	0.79	0.79	0.53	0.80
24	0.12	0.35	0.62	0.42	0.15	0.29
Average score	0.40	0.48	0.55	0.55	0.40	0.53

APPENDIX B

Bland and Altman plot frequencies

Difference in pitch velocity (deg/sec) within Visit 1, Trial 1 and Trial 2

Exercise	Median	Range	2.5th percentile	25th percentile	75th percentile	97.5th percentile	Interval of 50% of difference	Interval of 95% of difference
1	0.00	0.67	-0.26	-0.05	0.11	0.41	0.17	0.67
2	0.00	1.09	-0.33	-0.12	0.15	0.72	0.27	1.05
3	0.36	4.56	-1.96	-0.14	0.82	2.19	0.96	4.15
4	0.01	1.29	-0.40	-0.13	0.12	0.57	0.24	0.96
5	-0.03	2.55	-1.21	-0.19	0.18	0.91	0.37	2.13
6	0.16	10.24	-2.13	-0.23	0.65	5.20	0.88	7.33
7	0.00	1.59	-0.78	-0.07	0.06	0.46	0.12	1.25
8	0.04	1.74	-0.43	-0.11	0.28	1.16	0.39	1.59
9	0.36	7.90	-2.79	-0.27	0.87	3.37	1.14	6.16
10	-0.01	3.69	-1.04	-0.14	0.14	1.68	0.29	2.72
11	0.05	2.95	-1.53	-0.18	0.35	1.12	0.53	2.65
12	0.10	11.30	-1.88	-0.36	0.70	5.82	1.06	7.69
13	-0.03	1.21	-0.48	-0.12	0.06	0.50	0.17	0.98
14	0.11	2.25	-0.53	-0.07	0.22	1.60	0.29	2.14
15	0.21	8.17	-2.40	-0.19	0.66	5.34	0.85	7.74
16	-0.05	2.10	-1.14	-0.19	0.09	0.50	0.29	1.65
17	0.12	3.45	-0.79	-0.24	0.46	2.56	0.70	3.35
18	0.27	7.99	-2.63	-0.41	0.71	4.72	1.12	7.35
19	0.00	1.66	-0.39	-0.13	0.18	0.85	0.31	1.24
20	0.08	9.13	-3.95	-0.20	0.39	2.39	0.60	6.34
21	0.29	7.19	-2.75	-0.23	0.72	3.52	0.95	6.27
22	0.02	7.67	-3.90	-0.19	0.36	2.24	0.55	6.14
23	0.20	4.79	-3.39	-0.41	0.99	1.40	1.40	4.79
24	-0.07	8.94	-2.17	-0.88	0.65	6.70	1.53	8.87

Difference in pitch velocity (deg/sec) within Visit 2, Trial 3 and Trial 4

Exercise	Median	Range	2.5th percentile	25th percentile	75th percentile	97.5th percentile	Interval of 50% of difference	Interval of 95% of difference
1	0.03	1.18	-0.59	-0.07	0.10	0.36	0.17	0.95
2	0.04	1.28	-0.50	-0.09	0.19	0.61	0.27	1.11
3	0.07	10.48	-5.17	-0.19	0.26	2.12	0.45	7.29
4	0.01	3.80	-1.84	-0.11	0.10	0.58	0.22	2.42
5	0.00	3.20	-1.19	-0.20	0.20	1.56	0.41	2.75
6	-0.05	7.12	-3.08	-0.41	0.22	2.85	0.63	5.93
7	0.00	9.12	-3.64	-0.10	0.05	1.25	0.15	4.89
8	0.05	1.55	-0.51	-0.10	0.23	0.91	0.33	1.42
9	0.09	4.60	-1.53	-0.22	0.50	2.78	0.72	4.31
10	-0.02	1.71	-0.58	-0.16	0.10	0.91	0.26	1.49
11	0.06	4.29	-1.95	-0.29	0.36	1.83	0.65	3.78
12	0.04	4.04	-1.72	-0.35	0.62	2.11	0.96	3.83
13	0.00	1.48	-0.71	-0.16	0.11	0.67	0.28	1.38
14	0.01	3.13	-1.15	-0.28	0.16	1.44	0.44	2.59
15	0.03	7.10	-3.36	-0.51	0.53	1.95	1.04	5.31
16	0.08	7.13	-1.80	-0.07	0.23	2.87	0.30	4.67
17	-0.03	3.13	-1.92	-0.49	0.20	1.10	0.69	3.02
18	0.08	4.42	-2.58	-0.28	0.46	1.71	0.74	4.29
19	0.01	5.70	-2.36	-0.14	0.17	1.53	0.31	3.89
20	0.08	2.22	-0.75	-0.16	0.32	1.31	0.48	2.06
21	0.10	8.64	-2.32	-0.32	0.46	4.18	0.78	6.51
22	-0.09	6.34	-2.56	-0.35	0.24	2.85	0.59	5.40
23	0.07	5.56	-1.11	-0.12	0.50	4.40	0.61	5.51
24	0.00	5.79	-3.65	-0.78	0.64	2.10	1.43	5.75

Difference in pitch velocity (deg/sec) between visits, Trial 1 and Trial 3

Exercise	Median	Range	2.5th percentile	25th percentile	75th percentile	97.5th percentile	Interval of 50% of difference	Interval of 95% of difference
1	-0.01	1.23	-0.67	-0.12	0.05	0.40	0.17	1.07
2	0.03	1.40	-0.67	-0.16	0.14	0.51	0.29	1.18
3	0.35	6.47	-2.68	-0.34	0.85	3.27	1.20	5.96
4	-0.06	1.98	-0.77	-0.20	0.08	0.67	0.27	1.44
5	0.00	3.60	-1.60	-0.22	0.24	1.25	0.45	2.85
6	0.20	9.98	-2.55	-0.50	0.75	5.09	1.25	7.65
7	0.02	2.63	-1.34	-0.10	0.08	0.33	0.18	1.67
8	0.08	2.55	-0.84	-0.17	0.34	1.06	0.50	1.90
9	0.20	8.01	-3.82	-0.59	0.93	3.49	1.52	7.30
10	0.01	2.60	-0.60	-0.13	0.14	1.35	0.28	1.94
11	-0.05	2.46	-1.36	-0.40	0.35	0.96	0.74	2.32
12	0.30	10.24	-1.78	-0.17	0.82	5.48	0.99	7.26
13	-0.06	1.60	-0.74	-0.22	0.07	0.61	0.29	1.34
14	0.10	3.42	-0.87	-0.04	0.26	1.77	0.30	2.65
15	0.21	7.78	-2.20	-0.39	0.84	4.74	1.23	6.94
16	-0.11	3.58	-2.78	-0.41	0.11	0.56	0.52	3.34
17	0.07	5.02	-1.51	-0.27	0.71	3.27	0.98	4.79
18	0.04	8.54	-4.11	-0.38	0.53	4.03	0.90	8.14
19	0.01	4.63	-1.39	-0.15	0.19	1.41	0.34	2.80
20	0.14	4.86	-1.17	-0.18	0.52	2.45	0.70	3.62
21	0.24	10.00	-4.45	-0.59	1.19	3.28	1.78	7.73
22	-0.12	8.55	-4.54	-0.32	0.25	2.60	0.57	7.13
23	-0.13	2.91	-1.17	-0.34	0.58	1.70	0.92	2.87
24	-0.20	9.09	-1.81	-0.76	0.25	7.20	1.01	9.01

Difference in pitch velocity (deg/sec) between visits, Trial 2 and Trial 4

Exercise	Median	Range	2.5th percentile	25th percentile	75th percentile	97.5th percentile	Interval of 50% of difference	Interval of 95% of difference
1	-0.02	1.04	-0.62	-0.10	0.03	0.27	0.13	0.89
2	0.00	0.89	-0.41	-0.16	0.14	0.42	0.29	0.83
3	-0.04	8.36	-4.50	-0.70	0.40	2.12	1.10	6.62
4	-0.03	3.81	-2.04	-0.18	0.10	0.33	0.28	2.37
5	0.06	3.19	-1.29	-0.14	0.22	1.17	0.36	2.46
6	0.03	5.82	-3.07	-0.50	0.39	2.13	0.89	5.20
7	-0.02	7.88	-3.58	-0.11	0.08	0.73	0.19	4.31
8	0.03	1.15	-0.38	-0.10	0.16	0.66	0.26	1.04
9	0.15	6.20	-3.02	-0.37	0.64	2.51	1.02	5.53
10	-0.04	2.97	-0.70	-0.20	0.17	1.32	0.37	2.01
11	0.01	3.23	-2.11	-0.37	0.40	1.07	0.77	3.17
12	0.02	5.84	-1.73	-0.34	0.83	3.27	1.18	5.00
13	-0.02	1.37	-0.84	-0.16	0.06	0.38	0.22	1.22
14	0.02	1.89	-0.97	-0.12	0.23	0.55	0.35	1.52
15	0.02	10.31	-4.29	-0.44	0.49	2.46	0.93	6.76
16	-0.01	7.29	-2.77	-0.29	0.13	1.98	0.42	4.75
17	0.03	3.98	-2.50	-0.55	0.30	1.30	0.85	3.81
18	-0.14	5.77	-2.57	-0.58	0.30	3.11	0.88	5.68
19	0.01	2.93	-1.54	-0.14	0.14	0.50	0.28	2.04
20	0.21	2.69	-0.92	0.01	0.45	1.46	0.43	2.38
21	-0.05	5.89	-2.52	-0.64	0.51	3.19	1.15	5.71
22	-0.13	16.54	-7.04	-0.58	0.18	5.07	0.76	12.11
23	0.36	2.46	-0.75	-0.33	0.46	1.70	0.79	2.45
24	-0.10	6.02	-3.69	-0.83	0.35	2.30	1.19	5.99

Difference in roll velocity (deg/sec) within Visit 1, Trial 1 and Trial 2

Exercise	Median	Range	2.5th percentile	25th percentile	75th percentile	97.5th percentile	Interval of 50% of difference	Interval of 95% of difference
1	0.00	0.33	-0.14	-0.02	0.02	0.16	0.04	0.30
2	0.02	1.82	-0.88	-0.12	0.32	0.66	0.44	1.54
3	0.01	0.77	-0.24	-0.05	0.10	0.38	0.15	0.62
4	-0.03	1.81	-0.31	-0.08	0.03	0.86	0.11	1.17
5	-0.03	3.63	-1.58	-0.21	0.19	1.32	0.41	2.90
6	0.06	4.09	-1.30	-0.08	0.18	1.43	0.26	2.72
7	0.00	0.34	-0.09	-0.02	0.02	0.17	0.04	0.26
8	0.06	5.20	-1.12	-0.16	0.39	3.32	0.55	4.44
9	0.02	1.05	-0.47	-0.07	0.14	0.36	0.21	0.83
10	-0.04	3.36	-0.61	-0.13	0.05	1.54	0.17	2.15
11	-0.17	3.13	-1.71	-0.31	0.31	1.24	0.61	2.95
12	-0.03	3.48	-1.56	-0.23	0.19	1.59	0.42	3.15
13	-0.01	0.83	-0.45	-0.06	0.05	0.32	0.10	0.77
14	0.06	3.96	-0.64	-0.08	0.24	2.04	0.32	2.68
15	0.05	1.28	-0.46	-0.06	0.18	0.68	0.24	1.14
16	-0.05	1.92	-1.01	-0.19	0.15	0.72	0.33	1.73
17	0.27	4.39	-1.22	-0.21	1.16	3.00	1.37	4.21
18	0.02	3.62	-1.34	-0.30	0.40	2.13	0.71	3.47
19	-0.01	1.16	-0.56	-0.08	0.05	0.41	0.13	0.97
20	0.02	3.21	-1.38	-0.18	0.19	1.41	0.36	2.79
21	0.06	2.25	-0.40	-0.11	0.15	1.27	0.26	1.68
22	0.10	6.87	-3.10	-0.25	0.44	2.62	0.70	5.71
23	0.51	5.14	-2.50	-0.54	1.13	2.60	1.67	5.10
24	-0.09	8.39	-3.79	-0.86	0.98	4.60	1.85	8.39

Difference in roll velocity (deg/sec) within Visit 2, Trial 3 and Trial4

Exercise	Median	Range	2.5th percentile	25th percentile	75th percentile	97.5th percentile	Interval of 50% of difference	Interval of 95% of difference
1	-0.01	0.60	-0.14	-0.02	0.02	0.28	0.04	0.42
2	0.01	2.38	-1.13	-0.08	0.09	0.60	0.17	1.73
3	0.00	1.49	-0.65	-0.06	0.04	0.25	0.10	0.90
4	0.01	0.72	-0.27	-0.05	0.09	0.33	0.14	0.60
5	-0.02	2.94	-0.89	-0.15	0.14	1.23	0.29	2.12
6	-0.03	1.96	-0.64	-0.15	0.08	1.07	0.24	1.72
7	0.00	2.97	-1.21	-0.02	0.03	0.37	0.05	1.58
8	0.02	2.76	-1.05	-0.19	0.20	1.59	0.39	2.64
9	0.02	1.28	-0.25	-0.04	0.11	0.69	0.15	0.94
10	-0.02	1.15	-0.55	-0.10	0.07	0.36	0.17	0.91
11	-0.03	3.64	-1.66	-0.16	0.26	1.74	0.42	3.39
12	-0.03	4.06	-0.89	-0.23	0.19	2.13	0.42	3.02
13	0.00	0.96	-0.42	-0.07	0.06	0.34	0.13	0.76
14	-0.02	1.70	-0.86	-0.15	0.11	0.74	0.26	1.60
15	0.01	1.17	-0.46	-0.06	0.10	0.46	0.16	0.92
16	0.02	3.32	-0.69	-0.06	0.35	2.17	0.42	2.86
17	-0.16	4.32	-2.40	-0.48	0.40	1.60	0.88	4.01
18	0.01	4.38	-1.28	-0.32	0.28	2.65	0.59	3.93
19	0.02	3.58	-0.59	-0.05	0.06	1.45	0.12	2.05
20	-0.05	2.43	-0.88	-0.20	0.23	1.33	0.43	2.21
21	0.06	1.11	-0.40	-0.10	0.17	0.56	0.26	0.96
22	-0.02	3.49	-1.31	-0.33	0.34	1.94	0.67	3.25
23	-0.04	6.31	-1.52	-0.36	0.63	4.70	1.00	6.22
24	0.09	10.25	-7.78	-0.30	0.60	2.40	0.90	10.18

Difference in roll velocity (deg/sec) within visits, Trial 1 and Trial 3

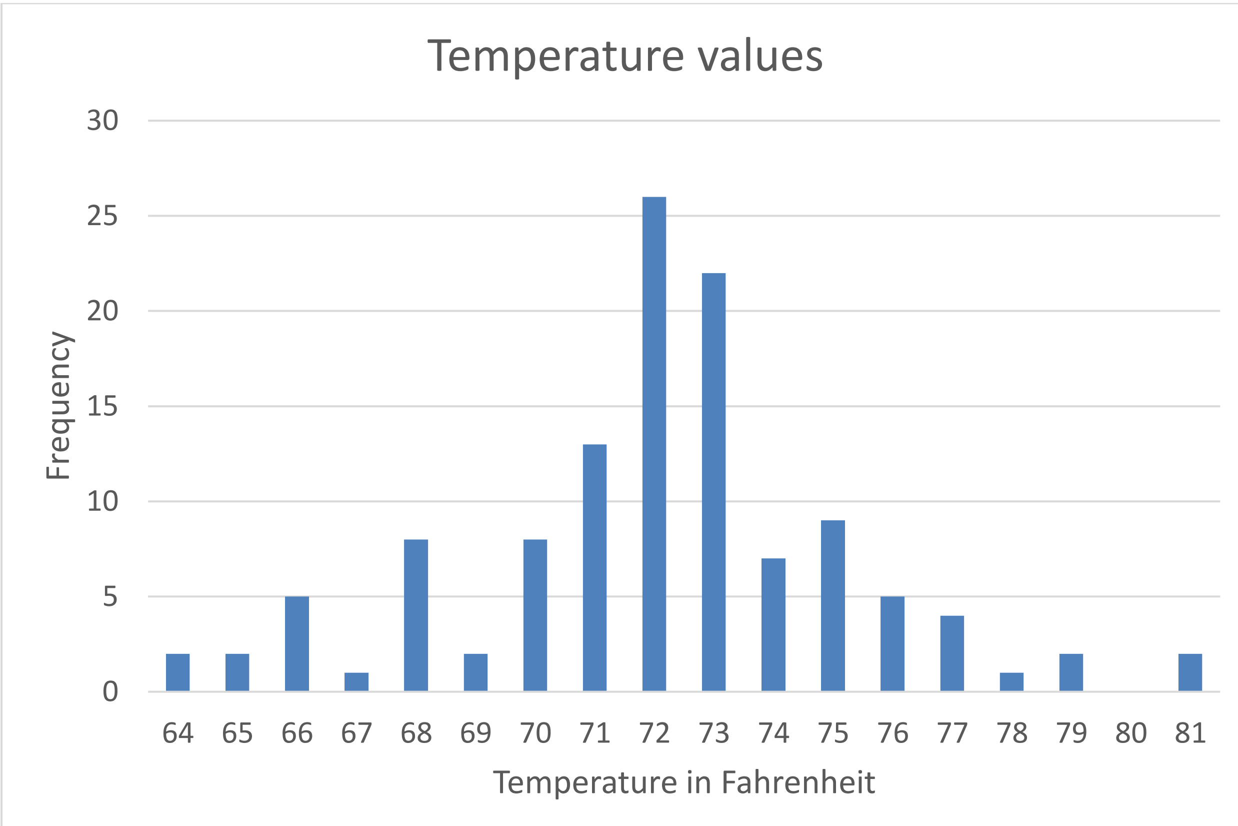
Exercise	Median	Range	2.5th percentile	25th percentile	75th percentile	97.5th percentile	Interval of 50% of difference	Interval of 95% of difference
1	0.00	0.75	-0.25	-0.04	0.02	0.25	0.06	0.50
2	0.07	2.25	-0.93	-0.07	0.30	1.03	0.36	1.96
3	0.04	1.63	-0.26	-0.03	0.11	0.73	0.15	0.99
4	0.00	2.72	-0.49	-0.12	0.05	1.18	0.17	1.67
5	0.06	3.07	-1.03	-0.16	0.34	1.42	0.51	2.44
6	0.11	4.55	-1.24	-0.07	0.21	1.72	0.29	2.96
7	0.01	1.15	-0.38	-0.03	0.03	0.39	0.05	0.77
8	0.15	7.34	-1.54	-0.19	0.49	3.83	0.68	5.38
9	0.02	1.16	-0.70	-0.08	0.22	0.34	0.31	1.04
10	0.01	2.80	-0.38	-0.07	0.09	1.45	0.16	1.83
11	-0.07	3.58	-1.67	-0.39	0.30	1.63	0.69	3.31
12	0.06	4.35	-1.94	-0.11	0.40	1.55	0.51	3.49
13	0.00	0.82	-0.38	-0.08	0.05	0.35	0.12	0.73
14	0.03	3.11	-0.76	-0.16	0.30	1.83	0.46	2.59
15	0.10	1.24	-0.27	-0.02	0.23	0.95	0.25	1.22
16	-0.12	3.54	-2.54	-0.44	0.15	0.81	0.58	3.36
17	0.32	6.35	-1.42	-0.18	0.81	4.35	0.99	5.77
18	0.05	3.14	-1.14	-0.37	0.50	1.85	0.87	2.99
19	0.01	3.17	-1.46	-0.05	0.05	0.45	0.10	1.91
20	0.17	4.77	-1.48	-0.19	0.70	2.32	0.89	3.80
21	0.04	2.31	-0.44	-0.11	0.25	1.37	0.36	1.81
22	0.03	8.74	-4.88	-0.20	0.26	2.30	0.46	7.18
23	0.39	5.90	-2.60	-0.18	1.37	3.30	1.54	5.90
24	0.16	6.18	-2.94	-1.28	1.01	3.20	2.29	6.14

Difference in roll velocity (deg/sec) within visits, Trial 2 and Trial 4

Exercise	Median	Range	2.5th percentile	25th percentile	75th percentile	97.5th percentile	Interval of 50% of difference	Interval of 95% of difference
1	0.00	0.47	-0.26	-0.02	0.02	0.14	0.04	0.40
2	0.04	2.73	-0.88	-0.20	0.18	1.33	0.37	2.21
3	0.01	0.73	-0.29	-0.04	0.09	0.34	0.13	0.63
4	0.01	0.98	-0.38	-0.04	0.06	0.50	0.11	0.89
5	0.11	3.86	-1.15	-0.09	0.25	1.65	0.34	2.80
6	0.04	2.94	-0.98	-0.15	0.16	1.15	0.31	2.13
7	0.00	2.38	-1.15	-0.02	0.02	0.09	0.05	1.25
8	0.10	2.99	-1.35	-0.12	0.33	1.38	0.45	2.72
9	0.05	0.76	-0.33	-0.04	0.15	0.39	0.19	0.72
10	0.00	2.02	-0.58	-0.07	0.11	0.78	0.18	1.36
11	0.08	3.93	-1.83	-0.20	0.43	1.79	0.63	3.62
12	0.07	3.46	-0.88	-0.10	0.34	2.19	0.44	3.06
13	-0.01	0.80	-0.39	-0.08	0.06	0.36	0.14	0.75
14	-0.03	2.54	-1.10	-0.25	0.16	1.01	0.41	2.11
15	0.08	1.26	-0.30	0.01	0.16	0.76	0.15	1.06
16	-0.03	5.26	-1.68	-0.27	0.16	1.82	0.43	3.50
17	0.01	7.75	-5.15	-0.51	0.51	1.45	1.03	6.60
18	-0.05	2.54	-1.20	-0.49	0.45	1.29	0.94	2.50
19	0.01	1.34	-0.56	-0.02	0.10	0.63	0.12	1.18
20	0.13	3.11	-1.00	-0.07	0.35	1.98	0.42	2.98
21	0.04	1.58	-0.39	-0.08	0.20	0.89	0.28	1.28
22	-0.15	9.97	-4.59	-0.47	0.19	3.11	0.66	7.70
23	0.10	4.58	-2.13	-0.61	1.11	2.40	1.72	4.53
24	0.24	11.19	-9.42	-0.52	0.68	1.70	1.20	11.12

APPENDIX C

THE TESTING LAB'S TEMPERATURE VALUES IN FAHRENHEIT



BIBLIOGRAPHY

Abellan, K. G., Rolland, Y., Andrieu, S., Bauer, J., Beauchet, O., Bonnefoy, M., . . . Vellas, B. (2009). Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging. *J Nutr Health Aging, 13*(10), 9.

Abellan van Kan, G., Rolland, Y., Andrieu, S., Bauer, J., Beauchet, O., Bonnefoy, M., . . . Vellas, B. (2009). Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. *J Nutr Health Aging, 13*(10), 881-889.

Abrahamova, D., & Hlavacka, F. (2008). Age-related changes of human balance during quiet stance. *Physiol Res, 57*(6), 957-964.

Agrawal, Y., Carey, J. P., Della Santina, C. C., Schubert, M. C., & Minor, L. B. (2009). Disorders of balance and vestibular function in US adults: data from the National Health and Nutrition Examination Survey, 2001-2004. *Arch Intern Med, 169*(10), 938-944. doi: 10.1001/archinternmed.2009.66

Alexander, B. H., Rivara, F. P., & Wolf, M. E. (1992). The cost and frequency of hospitalization for fall-related injuries in older adults. *Am J Public Health, 82*(7), 1020-1023.

Alexander, N. B. (1994). Postural control in older adults. *J Am Geriatr Soc, 42*(1), 93-108.

Allum, J. H., Carpenter, M. G., Horslen, B. C., Davis, J. R., Honegger, F., Tang, K. S., & Kessler, P. (2011). Improving impaired balance function: real-time versus carry-over effects of prosthetic feedback. *Conf Proc IEEE Eng Med Biol Soc, 2011*, 1314-1318. doi: 10.1109/IEMBS.2011.6090309

Alonso, A. C., Brech, G. C., Bourquin, A. M., & Greve, J. M. (2011). The influence of lower-limb dominance on postural balance. *Sao Paulo Med J, 129*(6), 410-413.

Alsalaheen, B. A., Whitney, S. L., Mucha, A., Morris, L. O., Furman, J. M., & Sparto, P. J. (2013). Exercise prescription patterns in patients treated with vestibular rehabilitation after concussion. *Physiotherapy Research International, 18*(2), 100-108. doi: 10.1002/pri.1532

American College of Sports, M. (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc, 41*(3), 687-708. doi: 10.1249/MSS.0b013e3181915670

Aniansson, A., Hedberg, M., Henning, G. B., & Grimby, G. (1986). Muscle morphology, enzymatic activity, and muscle strength in elderly men: a follow-up study. *Muscle Nerve, 9*(7), 585-591. doi: 10.1002/mus.880090702

Assaiante, C. a. A. B. (1992). Peripheral vision and age-related differences in dynamic balance. *Hum Mov Sci, 11*(5), 533-548.

Baloh, R. W., Fife, T. D., Zwerling, L., Socotch, T., Jacobson, K., Bell, T., & Beykirch, K. (1994). Comparison of static and dynamic posturography in young and older normal people. *J Am Geriatr Soc, 42*(4), 405-412.

Baloh, R. W., Jacobson, K. M., Enrietto, J. A., Corona, S., & Honrubia, V. (1998). Balance disorders in older persons: quantification with posturography. *Otolaryngol Head Neck Surg, 119*(1), 89-92.

Baloh, R. W., Ying, S. H., & Jacobson, K. M. (2003). A longitudinal study of gait and balance dysfunction in normal older people. *Arch Neurol, 60*(6), 835-839. doi: 10.1001/archneur.60.6.835

Barnett, A., Smith, B., Lord, S. R., Williams, M., & Baumand, A. (2003). Community-based group exercise improves balance and reduces falls in at-risk older people: a randomised controlled trial. *Age Ageing, 32*(4), 407-414.

Basta, D., Rossi-Izquierdo, M., Soto-Varela, A., Greters, M. E., Bittar, R. S., Steinhagen-Thiessen, E., . . . Ernst, A. (2011). Efficacy of a vibrotactile neurofeedback training in stance and gait conditions for the treatment of balance deficits: a double-blind, placebo-controlled multicenter study. *Otol Neurotol, 32*(9), 1492-1499. doi: 10.1097/MAO.0b013e31823827ec

Benvenuti, F., Mecacci, R., Gineprari, I., Bandinelli, S., Benvenuti, E., Ferrucci, L., . . . Stanhope, S. J. (1999). Kinematic characteristics of standing disequilibrium: reliability and validity of a posturographic protocol. *Arch Phys Med Rehabil, 80*(3), 278-287.

Berg, K. O., Maki, B. E., Williams, J. I., Holliday, P. J., & Wood-Dauphinee, S. L. (1992). Clinical and laboratory measures of postural balance in an elderly population. *Arch Phys Med Rehabil, 73*(11), 1073-1080.

Bergstrom, B. (1973). Morphology of the vestibular nerve. 3. Analysis of the calibers of the myelinated vestibular nerve fibers in man at various ages. *Acta Otolaryngol, 76*(5), 331-338.

Berry, S. D., & Miller, R. R. (2008). Falls: epidemiology, pathophysiology, and relationship to fracture. *Curr Osteoporos Rep, 6*(4), 149-154.

Black, F. O., Shupert, C. L., Peterka, R. J., & Nashner, L. M. (1989). Effects of unilateral loss of vestibular function on the vestibulo-ocular reflex and postural control. *Ann Otol Rhinol Laryngol, 98*(11), 884-889.

Bland, J. M., & Altman, D. G. (1995). Calculating correlation coefficients with repeated observations: Part 2--Correlation between subjects. *BMJ, 310*(6980), 633.

Bohannon, R. W. (1997). Comfortable and maximum walking speed of adults aged 20-79 years: reference values and determinants. *Age Ageing, 26*(1), 15-19.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Med Sci Sports Exerc, 14*(5), 377-381.

Borger, L. L., Whitney, S. L., Redfern, M. S., & Furman, J. M. (1999). The influence of dynamic visual environments on postural sway in the elderly. *J Vestib Res, 9*(3), 197-205.

Borkan, G. A., Hults, D. E., Gerzof, S. G., Robbins, A. H., & Silbert, C. K. (1983). Age changes in body composition revealed by computed tomography. *J Gerontol, 38*(6), 673-677.

Brian J. Benda, P. O. R., and David E. Krebs. (1994). Biomechanical Relationship Between Center of Gravity and Center of Pressure During Standing. *IEEE Trans on Rehab Eng, 2*(1), 8.

Brien Holden, T. F., Kovin Naidoo, Hasan Minto, Gerhard Schlenther, Sonja Cronje, Phil Hoare, Hannah Faal, Jerry Vincent, Clare Gilbert, Anthea Burnett, David Wilson, Prakash Paudel and REPCom. (2008). Strategy for the Elimination of Vision Impairment from Uncorrected Refractive Error. *Meeting of the Refractive Error Program Committee and IAPB Board of Trustees*.

Brodovsky, J. R., & Vnenchak, M. J. (2013). Vestibular rehabilitation for unilateral peripheral vestibular dysfunction. *Phys Ther, 93*(3), 293-298. doi: 10.2522/ptj.20120057

Caraffa, A., Cerulli, G., Projetti, M., Aisa, G., & Rizzo, A. (1996). Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee Surg Sports Traumatol Arthrosc, 4*(1), 19-21.

Cawthorne, T. (1946). Vestibular Injuries. *Proc R Soc Med, 39*(5), 270-273.

Centers for Disease, C., & Prevention. (2008). Self-reported falls and fall-related injuries among persons aged > or =65 years--United States, 2006. *MMWR Morb Mortal Wkly Rep, 57*(9), 225-229.

Chang, C. J., Chang, Y. S., & Yang, S. W. (2013). Using single leg standing time to predict the fall risk in elderly. *Conf Proc IEEE Eng Med Biol Soc, 2013*, 7456-7458. doi: 10.1109/EMBC.2013.6611282

Chang, C. J., Chang, Y. S., & Yang, S. W. (2013). Using single leg standing time to predict the fall risk in elderly. *Conf Proc IEEE Eng Med Biol Soc*, 7456-7458.

Chia-Cheng Lin, J. L. R., Denial P. Steed, Mark C. Musolino, Gregory F. Marchetti, Mark S. Redfern, Susan L. Whitney. (2014). Test-retest reliability of postural stability on two different foam pads. *personal communication*.

Chiari, L., Dozza, M., Cappello, A., Horak, F. B., Macellari, V., & Giansanti, D. (2005). Audio-biofeedback for balance improvement: an accelerometry-based system. *IEEE Trans Biomed Eng, 52*(12), 2108-2111. doi: 10.1109/TBME.2005.857673

Cnters for Disease, C., & Prevention. (2016). Important Facts about Falls.

Cohen, H., Heaton, L. G., Congdon, S. L., & Jenkins, H. A. (1996). Changes in sensory organization test scores with age. *Age Ageing, 25*(1), 39-44.

Colledge, N. R., Cantley, P., Peaston, I., Brash, H., Lewis, S., & Wilson, J. A. (1994). Ageing and balance: the measurement of spontaneous sway by posturography. *Gerontology, 40*(5), 273-278.

Corriveau, H., Hebert, R., Prince, F., & Raiche, M. (2000). Intrasession reliability of the "center of pressure minus center of mass" variable of postural control in the healthy elderly. *Arch Phys Med Rehabil, 81*(1), 45-48.

Danis, C. G., Krebs, D. E., Gill-Body, K. M., & Sahrmann, S. (1998). Relationship between standing posture and stability. *Phys Ther, 78*(5), 502-517.

Davis, J. R., Carpenter, M. G., Tschanz, R., Meyes, S., Debrunner, D., Burger, J., & Allum, J. H. (2010). Trunk sway reductions in young and older adults using multi-modal biofeedback. *Gait Posture, 31*(4), 465-472. doi: 10.1016/j.gaitpost.2010.02.002

Day, B. L., Guerraz, M., & Cole, J. (2002). Sensory interactions for human balance control revealed by galvanic vestibular stimulation. *Adv Exp Med Biol, 508*, 129-137.

Dean, J. C., Kuo, A. D., & Alexander, N. B. (2004). Age-related changes in maximal hip strength and movement speed. *J Gerontol A Biol Sci Med Sci, 59*(3), 286-292.

Dix, M. R., & Hallpike, C. S. (1952). The pathology, symptomatology and diagnosis of certain common disorders of the vestibular system. *Ann Otol Rhinol Laryngol, 61*(4), 987-1016.

Doyle, R. J., Hsiao-Wecksler, E. T., Ragan, B. G., & Rosengren, K. S. (2007). Generalizability of center of pressure measures of quiet standing. *Gait Posture, 25*(2), 166-171. doi: 10.1016/j.gaitpost.2006.03.004

Dozza, M., Chiari, L., & Horak, F. B. (2005). Audio-biofeedback improves balance in patients with bilateral vestibular loss. *Arch Phys Med Rehabil, 86*(7), 1401-1403.

Dozza, M., Horak, F. B., & Chiari, L. (2007). Auditory biofeedback substitutes for loss of sensory information in maintaining stance. *Exp Brain Res, 178*(1), 37-48. doi: 10.1007/s00221-006-0709-y

Dozza, M., Wall, C., 3rd, Peterka, R. J., Chiari, L., & Horak, F. B. (2007). Effects of practicing tandem gait with and without vibrotactile biofeedback in subjects with unilateral vestibular loss. *J Vestib Res, 17*(4), 195-204.

Dunn, O. J. (1961). Multiple Comparisons Among Means. *Journal of the American Statistical Association, 56*(293), 13.

Dunn, O. J. (1964). Multiple Comparisons Using Rank Sums. *Technometrics, 6*(3), 12.

Emery, C. A., Rose, M. S., McAllister, J. R., & Meeuwisse, W. H. (2007). A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial. *Clin J Sport Med, 17*(1), 17-24. doi: 10.1097/JSM.0b013e31802e9c05

Enrietto, J. A., Jacobson, K. M., & Baloh, R. W. (1999). Aging effects on auditory and vestibular responses: a longitudinal study. *Am J Otolaryngol, 20*(6), 371-378.

Era, P., Sainio, P., Koskinen, S., Haavisto, P., Vaara, M., & Aromaa, A. (2006). Postural balance in a random sample of 7,979 subjects aged 30 years and over. *Gerontology, 52*(4), 204-213. doi: 10.1159/000093652

Espy, D., Reinthal, A., Kuchta, N., Casey, N., & Wiland, T. (2015). *Development of a Rating Scale for Perceived Stability During Balance Training*. Paper presented at the Combined Sections Meeting, Indianapolis, Indians.

Farlie, M. K., Molloy, E., Keating, J. L., & Haines, T. P. (2016). Clinical Markers of the Intensity of Balance Challenge: Observational Study of Older Adult Responses to Balance Tasks. *Phys Ther, 96*(3), 313-323. doi: 10.2522/ptj.20140524

Farlie, M. K., Robins, L., Keating, J. L., Molloy, E., & Haines, T. P. (2013). Intensity of challenge to the balance system is not reported in the prescription of balance exercises in randomised trials: a systematic review. *J Physiother, 59*(4), 227-235. doi: 10.1016/S1836-9553(13)70199-1

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods, 39*(2), 175-191.

Fernie, G. R., Gryfe, C. I., Holliday, P. J., & Llewellyn, A. (1982). The relationship of postural sway in standing to the incidence of falls in geriatric subjects. *Age Ageing, 11*(1), 11-16.

Fisher, S. T. (2010). The intra-session and inter-session reliability of centre-of-pressure based measures of postural sway within a normal population. *UNITEC Institute of Technology*.

Fleiss, J. L. (1999). The Design and Analysis of Clinical Experiments. *A Wiley-Interscience Publication*.

Forsen, L., Sogaard, A. J., Meyer, H. E., Edna, T., & Kopjar, B. (1999). Survival after hip fracture: short- and long-term excess mortality according to age and gender. *Osteoporos Int, 10*(1), 73-78.

Franco, M. R., Pereira, L. S., & Ferreira, P. H. (2014). Exercise interventions for preventing falls in older people living in the community. *Br J Sports Med, 48*(10), 867-868. doi: 10.1136/bjsports-2012-092065

Fujimoto, C., Egami, N., Kinoshita, M., Sugasawa, K., Yamasoba, T., & Iwasaki, S. (2014). Postural stability in vestibular neuritis: age, disease duration, and residual vestibular function. *Laryngoscope, 124*(4), 974-979. doi: 10.1002/lary.24342

Furman, J. M., Cass, S. P., & Whitney, S. L. (2010). *Vestibular Disorders: A Case Study Approach to Diagnosis and Treatment* (Vol. 1): Oxford University Press.

Gabbard, C., & Hart, S. (1996). A question of foot dominance. *J Gen Psychol, 123*(4), 289-296. doi: 10.1080/00221309.1996.9921281

Garcia, A. P., Gananca, M. M., Cusin, F. S., Tomaz, A., Gananca, F. F., & Caovilla, H. H. (2013). Vestibular rehabilitation with virtual reality in Meniere's disease. *Braz J Otorhinolaryngol, 79*(3), 366-374. doi: 10.5935/1808-8694.20130064

Gill-Body, K. M., Krebs, D. E., Parker, S. W., & Riley, P. O. (1994). Physical therapy management of peripheral vestibular dysfunction: two clinical case reports. *Phys Ther, 74*(2), 129-142.

Gill, J., Allum, J. H., Carpenter, M. G., Held-Ziolkowska, M., Adkin, A. L., Honegger, F., & Pierchala, K. (2001). Trunk sway measures of postural stability during clinical balance tests: effects of age. *J Gerontol A Biol Sci Med Sci, 56*(7), M438-447.

Gillespie, L. D., Robertson, M. C., Gillespie, W. J., Sherrington, C., Gates, S., Clemson, L. M., & Lamb, S. E. (2012). Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev*(9), CD007146. doi: 10.1002/14651858.CD007146.pub3

Giray, M., Kirazli, Y., Karapolat, H., Celebisoy, N., Bilgen, C., & Kirazli, T. (2009). Short-term effects of vestibular rehabilitation in patients with chronic unilateral vestibular dysfunction: a randomized controlled study. *Arch Phys Med Rehabil, 90*(8), 1325-1331. doi: 10.1016/j.apmr.2009.01.032

Gittings, N. S., & Fozard, J. L. (1986). Age related changes in visual acuity. *Exp Gerontol, 21*(4-5), 423-433.

Goldie, P. A., Bach, T. M., & Evans, O. M. (1989). Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehabil, 70*(7), 510-517.

Haggerty, S., Jiang, L. T., Galecki, A., & Sienko, K. H. (2012). Effects of biofeedback on secondary-task response time and postural stability in older adults. *Gait Posture, 35*(4), 523-528. doi: 10.1016/j.gaitpost.2011.10.359

Hall, C. D., & Herdman, S. J. (2006). Reliability of clinical measures used to assess patients with peripheral vestibular disorders. *J Neurol Phys Ther, 30*(2), 74-81.

Hall, C. D., Herdman, S. J., Whitney, S. L., Cass, S. P., Clendaniel, R. A., Fife, T. D., . . . Woodhouse, S. N. (2016). Vestibular Rehabilitation for Peripheral Vestibular Hypofunction: An Evidence-Based Clinical Practice Guideline: FROM THE AMERICAN PHYSICAL THERAPY ASSOCIATION NEUROLOGY SECTION. *J Neurol Phys Ther, 40*(2), 124-155. doi: 10.1097/NPT.0000000000000120

Halmagyi, G. M., & Curthoys, I. S. (1988). A clinical sign of canal paresis. *Arch Neurol, 45*(7), 737-739.

Halmagyi, G. M., Weber, K. P., & Curthoys, I. S. (2010). Vestibular function after acute vestibular neuritis. *Restor Neurol Neurosci, 28*(1), 37-46. doi: 10.3233/RNN-2010-0533

Han, B. I., Song, H. S., & Kim, J. S. (2011). Vestibular rehabilitation therapy: review of indications, mechanisms, and key exercises. *J Clin Neurol, 7*(4), 184-196. doi: 10.3988/jcn.2011.7.4.184

Han, J. T., Lee, M. H., & Lee, K. H. (2013). Effects of Local Muscle Vibration on the Displacement of Center of Pressure during Quiet Standing. *J Phys Ther Sci, 25*(12), 1643-1645. doi: 10.1589/jpts.25.1643

Hays, R. D., Morales, L. S., & Reise, S. P. (2000). Item response theory and health outcomes measurement in the 21st century. *Med Care, 38*(9 Suppl), II28-42.

Heebner, N. R., Akins, J. S., Lephart, S. M., & Sell, T. C. (2015). Reliability and validity of an accelerometry based measure of static and dynamic postural stability in healthy and active individuals. *Gait Posture, 41*(2), 535-539. doi: 10.1016/j.gaitpost.2014.12.009

Hegeman, J., Honegger, F., Kupper, M., & Allum, J. H. (2005). The balance control of bilateral peripheral vestibular loss subjects and its improvement with auditory prosthetic feedback. *J Vestib Res, 15*(2), 109-117.

Helbostad, J. L., Sturnieks, D. L., Menant, J., Delbaere, K., Lord, S. R., & Pijnappels, M. (2010). Consequences of lower extremity and trunk muscle fatigue on balance and functional tasks in older people: a systematic literature review. *BMC Geriatr, 10*, 56. doi: 10.1186/1471-2318-10-56

Helmchen, C., Klinkenstein, J. C., Kruger, A., Gliemroth, J., Mohr, C., & Sander, T. (2011). Structural brain changes following peripheral vestibulo-cochlear lesion may indicate multisensory compensation. *J Neurol Neurosurg Psychiatry, 82*(3), 309-316. doi: 10.1136/jnnp.2010.204925

Herdman, S. J. (1998). Role of vestibular adaptation in vestibular rehabilitation. *Otolaryngol Head Neck Surg, 119*(1), 49-54.

Herdman, S. J., & Clendaniel, R. A. (2014). *Vestibular Rehabilitation* F. A. Davis Company.

Herdman, S. J., Clendaniel, R. A., Mattox, D. E., Holliday, M. J., & Niparko, J. K. (1995). Vestibular adaptation exercises and recovery: acute stage after acoustic neuroma resection. *Otolaryngol Head Neck Surg, 113*(1), 77-87.

Herdman, S. J., Hall, C. D., Schubert, M. C., Das, V. E., & Tusa, R. J. (2007). Recovery of dynamic visual acuity in bilateral vestibular hypofunction. *Arch Otolaryngol Head Neck Surg, 133*(4), 383-389. doi: 10.1001/archotol.133.4.383

Herdman, S. J., & Tusa, R. J. (2007). Physical therapy management of benign positional vertigo. *Vestibular Rehabilitation*.

Hertel, J., Olmsted-Kramer, L. C., & Challis, J. H. (2006). Time-to-boundary measures of postural control during single leg quiet standing. *J Appl Biomech, 22*(1), 67-73.

Hilliard, M. J., Martinez, K. M., Janssen, I., Edwards, B., Mille, M. L., Zhang, Y., & Rogers, M. W. (2008). Lateral balance factors predict future falls in community-living older adults. *Archives of Physical Medicine & Rehabilitation, 89*(9), 1708-1713. doi: 10.1016/j.apmr.2008.01.023

Hillier, S. L., & McDonnell, M. (2011). Vestibular rehabilitation for unilateral peripheral vestibular dysfunction. *Cochrane Database Syst Rev*(2), CD005397. doi: 10.1002/14651858.CD005397.pub3

Holewski, J. J., Stess, R. M., Graf, P. M., & Grunfeld, C. (1988). Aesthesiometry: quantification of cutaneous pressure sensation in diabetic peripheral neuropathy. *J Rehabil Res Dev, 25*(2), 1-10.

Hong, H. R., Shim, D. B., Kim, T. S., Shim, B. S., Ahn, J. H., Chung, J. W., . . . Park, H. J. (2013). Results of caloric and sensory organization testing of dynamic posturography in migrainous vertigo: comparison with Meniere's disease and vestibular neuritis. *Acta Otolaryngol, 133*(12), 1236-1241. doi: 10.3109/00016489.2013.820343

Horak, F. B. (1987). Clinical measurement of postural control in adults. *Phys Ther, 67*(12), 1881-1885.

Horak, F. B. (2006). Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? *Age Ageing, 35 Suppl 2*, ii7-ii11. doi: 10.1093/ageing/afl077

Horak, F. B., Dozza, M., Peterka, R., Chiari, L., & Wall, C., 3rd. (2009). Vibrotactile biofeedback improves tandem gait in patients with unilateral vestibular loss. *Ann N Y Acad Sci, 1164*, 279-281. doi: 10.1111/j.1749-6632.2008.03707.x

Horak, F. B., Jones-Rycewicz, C., Black, F. O., & Shumway-Cook, A. (1992). Effects of vestibular rehabilitation on dizziness and imbalance. *Otolaryngol Head Neck Surg, 106*(2), 175-180.

Hornyak, V., VanSwearingen, J. M., & Brach, J. S. (2012). Measurement of Gait Speed. *Topics in Geriatric Rehabilitation, 28*(1), 6.

Howe, T. E., Rochester, L., Neil, F., Skelton, D. A., & Ballinger, C. (2011). Exercise for improving balance in older people. *Cochrane Database Syst Rev*(11), CD004963. doi: 10.1002/14651858.CD004963.pub3

Huang, T. T., & Wang, W. S. (2009). Comparison of three established measures of fear of falling in community-dwelling older adults: psychometric testing. *Int J Nurs Stud, 46*(10), 1313-1319. doi: 10.1016/j.ijnurstu.2009.03.010

Hufschmidt, A., Dichgans, J., Mauritz, K. H., & Hufschmidt, M. (1980). Some methods and parameters of body sway quantification and their neurological applications. *Arch Psychiatr Nervenkr (1970), 228*(2), 135-150.

Hytonen, M., Pyykko, I., Aalto, H., & Starck, J. (1993). Postural control and age. *Acta Otolaryngol, 113*(2), 119-122.

J., P. D. (2012). THE EFFECT OF DIFFERENT FOAMS ON POSTUROGRAPHY MEASURES IN HEALTHY AND IMPAIRED POPULATIONS. *Stander Symposium Posters*.

Jacobson, G. P., & Newman, C. W. (1990). The development of the Dizziness Handicap Inventory. *Arch Otolaryngol Head Neck Surg, 116*(4), 424-427.

Jongkees, L. B., Maas, J. P., & Philipszoon, A. J. (1962). Clinical nystagmography. A detailed study of electro-nystagmography in 341 patients with vertigo. *Pract Otorhinolaryngol (Basel), 24*, 65-93.

Judge, J. O., King, M. B., Whipple, R., Clive, J., & Wolfson, L. I. (1995). Dynamic balance in older persons: effects of reduced visual and proprioceptive input. *J Gerontol A Biol Sci Med Sci, 50*(5), M263-270.

Jung, J. Y., Kim, J. S., Chung, P. S., Woo, S. H., & Rhee, C. K. (2009). Effect of vestibular rehabilitation on dizziness in the elderly. *Am J Otolaryngol, 30*(5), 295-299. doi: 10.1016/j.amjoto.2008.06.013

Kaplan, F. S., Nixon, J. E., Reitz, M., Rindfleish, L., & Tucker, J. (1985). Age-related changes in proprioception and sensation of joint position. *Acta Orthop Scand, 56*(1), 72-74.

Kentala, E., Vivas, J., & Wall, C., 3rd. (2003). Reduction of postural sway by use of a vibrotactile balance prosthesis prototype in subjects with vestibular deficits. *Ann Otol Rhinol Laryngol, 112*(5), 404-409.

Kerber, K. A., Ishiyama, G. P., & Baloh, R. W. (2006). A longitudinal study of oculomotor function in normal older people. *Neurobiol Aging, 27*(9), 1346-1353. doi: 10.1016/j.neurobiolaging.2005.07.009

Klatt, B. N., Carender, W. J., Lin, C. C., Alsubaie, S. F., Kinnaird, C. R., Sienko, K. H., & Whitney, S. L. (2015). A Conceptual Framework for the Progression of Balance Exercises in Persons with Balance and Vestibular Disorders. *Physical Medicine and Rehabilitation - International*, *2*(4).

Koller, W. C., Wilson, R. S., Glatt, S. L., Huckman, M. S., & Fox, J. R. (1983). Senile gait: correlation with computed tomographic scans. *Ann Neurol, 13*(3), 343-344. doi: 10.1002/ana.410130326

Kristinsdottir, E. K., Jarnlo, G. B., & Magnusson, M. (2000). Asymmetric vestibular function in the elderly might be a significant contributor to hip fractures. *Scand J Rehabil Med, 32*(2), 56-60.

Kristinsdottir, E. K., Nordell, E., Jarnlo, G. B., Tjader, A., Thorngren, K. G., & Magnusson, M. (2001). Observation of vestibular asymmetry in a majority of patients over 50 years with fall-related wrist fractures. *Acta Otolaryngol, 121*(4), 481-485.

Lafond, D., Corriveau, H., Hebert, R., & Prince, F. (2004). Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. *Arch Phys Med Rehabil, 85*(6), 896-901.

Lajoie, Y., & Gallagher, S. P. (2004). Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers. *Arch Gerontol Geriatr, 38*(1), 11-26.

Larsson, L., Grimby, G., & Karlsson, J. (1979). Muscle strength and speed of movement in relation to age and muscle morphology. *J Appl Physiol Respir Environ Exerc Physiol, 46*(3), 451-456.

Le Clair, K., & Riach, C. (1996). Postural stability measures: what to measure and for how long. *Clin Biomech (Bristol, Avon), 11*(3), 176-178.

Lee, B. C., Kim, J., Chen, S., & Sienko, K. H. (2012). Cell phone based balance trainer. *J Neuroeng Rehabil, 9*, 10. doi: 10.1186/1743-0003-9-10

Lempert, T., & Tiel-Wilck, K. (1996). A positional maneuver for treatment of horizontal-canal benign positional vertigo. *Laryngoscope, 106*(4), 476-478.

Liaw, M. Y., Chen, C. L., Pei, Y. C., Leong, C. P., & Lau, Y. C. (2009). Comparison of the static and dynamic balance performance in young, middle-aged, and elderly healthy people. *Chang Gung Med J, 32*(3), 297-304.

Lichtenstein, M. J., Burger, M. C., Shields, S. L., & Shiavi, R. G. (1990). Comparison of biomechanics platform measures of balance and videotaped measures of gait with a clinical mobility scale in elderly women. *J Gerontol, 45*(2), M49-54.

Lichtenstein, M. J., Shields, S. L., Shiavi, R. G., & Burger, M. C. (1988). Clinical determinants of biomechanics platform measures of balance in aged women. *J Am Geriatr Soc, 36*(11), 996-1002.

Lin, C. C. (2014). The Effect of Vibrotactile Feedback on Healthy People and People with Vestibular Disorders during Dual-task Conditions. 65-74. Retrieved from D-Scholarship@Pitt website:

Lin, C. C., Roche, J. L., Steed, D. P., Musolino, M. C., Marchetti, G. F., Furman, G. R., . . . Whitney, S. L. (2015). Test-retest reliability of postural stability on two different foam pads. *J Nat Sci, 1*(2), e43.

Lin, D., Seol, H., Nussbaum, M. A., & Madigan, M. L. (2008). Reliability of COP-based postural sway measures and age-related differences. *Gait Posture, 28*(2), 337-342. doi: 10.1016/j.gaitpost.2008.01.005

Littell, R. C., Pendergast, J., & Natarajan, R. (2000). Modelling covariance structure in the analysis of repeated measures data. *Stat Med, 19*(13), 1793-1819.

Lord, S. R. (2006). Visual risk factors for falls in older people. *Age Ageing, 35 Suppl 2*, ii42-ii45. doi: 10.1093/ageing/afl085

Lord, S. R., Clark, R. D., & Webster, I. W. (1991a). Postural stability and associated physiological factors in a population of aged persons. *J Gerontol, 46*(3), M69-76.

Lord, S. R., Clark, R. D., & Webster, I. W. (1991b). Visual acuity and contrast sensitivity in relation to falls in an elderly population. *Age Ageing, 20*(3), 175-181.

Lord, S. R., & Dayhew, J. (2001). Visual risk factors for falls in older people. *J Am Geriatr Soc, 49*(5), 508-515.

Lord, S. R., & Ward, J. A. (1994). Age-associated differences in sensori-motor function and balance in community dwelling women. *Age Ageing, 23*(6), 452-460.

Lusardi, M. M., Marjorie, G. L., & Schulman, M. (2003). Functional Performance in Community Living Older Adults. *J Geriatr Phys Ther, 26*(3), 9.

Maki, B. E., Holliday, P. J., & Topper, A. K. (1994). A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *J Gerontol, 49*(2), M72-84.

Marchetti, G. F., Whitney, S. L., Redfern, M. S., & Furman, J. M. (2011). Factors associated with balance confidence in older adults with health conditions affecting the balance and vestibular system. *Arch Phys Med Rehabil, 92*(11), 1884-1891. doi: 10.1016/j.apmr.2011.06.015

Maylor, E. A., & Wing, A. M. (1996). Age differences in postural stability are increased by additional cognitive demands. *J Gerontol B Psychol Sci Soc Sci, 51*(3), P143-154.

McIlroy, W. E., & Maki, B. E. (1997). Preferred placement of the feet during quiet stance: development of a standardized foot placement for balance testing. *Clin Biomech (Bristol, Avon), 12*(1), 66-70.

Meldrum, D., Glennon, A., Herdman, S., Murray, D., & McConn-Walsh, R. (2012). Virtual reality rehabilitation of balance: assessment of the usability of the Nintendo Wii((R)) Fit Plus. *Disabil Rehabil Assist Technol, 7*(3), 205-210. doi: 10.3109/17483107.2011.616922

Meldrum, D., Herdman, S., Moloney, R., Murray, D., Duffy, D., Malone, K., . . . McConn-Walsh, R. (2012). Effectiveness of conventional versus virtual reality based vestibular rehabilitation in the treatment of dizziness, gait and balance impairment in adults with unilateral peripheral vestibular loss: a randomised controlled trial. *BMC Ear Nose Throat Disord, 12*, 3. doi: 10.1186/1472-6815-12-3

Michelle M. Lusardi, G. L. P., Marjorie Schulman. (2003). Functional Performance in Community Living Older Adults. *J Geriatr Phys Ther, 26*(3), 9.

Moe-Nilssen, R. (1998). Test-retest reliability of trunk accelerometry during standing and walking. *Arch Phys Med Rehabil, 79*(11), 1377-1385.

Moreland, J. D., Richardson, J. A., Goldsmith, C. H., & Clase, C. M. (2004). Muscle weakness and falls in older adults: a systematic review and meta-analysis. *J Am Geriatr Soc, 52*(7), 1121-1129. doi: 10.1111/j.1532-5415.2004.52310.x

Muehlbauer, T., Roth, R., Bopp, M., & Granacher, U. (2012). An exercise sequence for progression in balance training. *J Strength Cond Res, 26*(2), 568-574. doi: 10.1519/JSC.0b013e318225f3c4

Muhammad, N., Alhassan, M. B., & Umar, M. M. (2015). Visual function and vision-related quality of life in presbyopic adult population of Northwestern Nigeria. *Niger Med J, 56*(5), 317-322. doi: 10.4103/0300-1652.170379

Myers, A. M., Fletcher, P. C., Myers, A. H., & Sherk, W. (1998). Discriminative and evaluative properties of the activities-specific balance confidence (ABC) scale. *J Gerontol A Biol Sci Med Sci, 53*(4), M287-294.

Nadkarni, N. K., Studenski, S. A., Perera, S., Rosano, C., Aizenstein, H. J., Brach, J. S., & Van Swearingen, J. M. (2013). White matter hyperintensities, exercise, and improvement in gait speed: does type of gait rehabilitation matter? *J Am Geriatr Soc, 61*(5), 686-693. doi: 10.1111/jgs.12211

Nanhoe-Mahabier, W., Allum, J. H., Pasman, E. P., Overeem, S., & Bloem, B. R. (2012). The effects of vibrotactile biofeedback training on trunk sway in Parkinson's disease patients. *Parkinsonism Relat Disord, 18*(9), 1017-1021. doi: 10.1016/j.parkreldis.2012.05.018

Nardone, A., Tarantola, J., Giordano, A., & Schieppati, M. (1997). Fatigue effects on body balance. *Electroencephalogr Clin Neurophysiol, 105*(4), 309-320.

Nasreddine, Z. S., Phillips, N. A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *J Am Geriatr Soc, 53*(4), 695-699. doi: 10.1111/j.1532-5415.2005.53221.x

Nejc, S., Jernej, R., Loefler, S., & Kern, H. (2010). Sensitivity of body sway parameters during quiet standing to manipulation of support surface size. *J Sports Sci Med, 9*(3), 431-438.

Nguyen, U. S., Kiel, D. P., Li, W., Galica, A. M., Kang, H. G., Casey, V. A., & Hannan, M. T. (2012). Correlations of clinical and laboratory measures of balance in older men and women. *Arthritis Care Res (Hoboken), 64*(12), 1895-1902. doi: 10.1002/acr.21783

Nitz, J. C., & Choy, N. L. (2004). The efficacy of a specific balance-strategy training programme for preventing falls among older people: a pilot randomised controlled trial. *Age Ageing, 33*(1), 52-58.

Noble, B. J., & Robertson, R. J. (1996). *Perceived Exertion*: Human Kinetics.

O'Connor, K. W., Loughlin, P. J., Redfern, M. S., & Sparto, P. J. (2008). Postural adaptations to repeated optic flow stimulation in older adults. *Gait Posture, 28*(3), 385-391. doi: 10.1016/j.gaitpost.2008.01.010

O'Sullivan, M., Blake, C., Cunningham, C., Boyle, G., & Finucane, C. (2009). Correlation of accelerometry with clinical balance tests in older fallers and non-fallers. *Age Ageing, 38*(3), 308-313. doi: 10.1093/ageing/afp009

Oliveira, C. B., Medeiros, I. R., Greters, M. G., Frota, N. A., Lucato, L. T., Scaff, M., & Conforto, A. B. (2011). Abnormal sensory integration affects balance control in hemiparetic patients within the first year after stroke. *Clinics (Sao Paulo), 66*(12), 2043-2048.

Overstall, P. W., Exton-Smith, A. N., Imms, F. J., & Johnson, A. L. (1977). Falls in the elderly related to postural imbalance. *Br Med J, 1*(6056), 261-264.

Parietti-Winkler, C., Gauchard, G. C., Simon, C., & Perrin, P. P. (2010). Long-term effects of vestibular compensation on balance control and sensory organisation after unilateral deafferentation due to vestibular schwannoma surgery. *J Neurol Neurosurg Psychiatry, 81*(8), 934-936. doi: 10.1136/jnnp.2009.171983

Patel, M., Fransson, P. A., Lush, D., & Gomez, S. (2008). The effect of foam surface properties on postural stability assessment while standing. *Gait Posture, 28*(4), 649-656. doi: 10.1016/j.gaitpost.2008.04.018

Pavlou, M. (2010). The use of optokinetic stimulation in vestibular rehabilitation. *J Neurol Phys Ther, 34*(2), 105-110. doi: 10.1097/NPT.0b013e3181dde6bf

Pescatello, L. S., & American College of Sports Medicine. (2014). *ACSM's guidelines for exercise testing and prescription* (9th ed.). Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health.

Peterka, R. J., & Black, F. O. (1990). Age-related changes in human posture control: sensory organization tests. *J Vestib Res, 1*(1), 73-85.

Peterka, R. J., Black, F. O., & Schoenhoff, M. B. (1990). Age-related changes in human vestibulo-ocular reflexes: sinusoidal rotation and caloric tests. *J Vestib Res, 1*(1), 49-59.

Petit, D. J. (2012a). The Effect of Different Foams on Posturography Measures in Healthy and Impaired Populations. *Stander Symposium Posters*.

Petit, D. J. (2012b). The Effect of Different Foams on Posturography Measures in Healthy and Impaired Populations. *Stander Symposium Posters. Book 132*.

Powell, L. E., & Myers, A. M. (1995). The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol A Biol Sci Med Sci, 50A*(1), M28-34.

Public-Health-Agency-of-Canada. (2014). Seniors' Falls in Canada: Second Report.

Rafal, S., Janusz, M., Wieslaw, O., & Robert, S. (2011). Test-retest reliability of measurements of the center of pressure displacement in quiet standing and during maximal voluntary body leaning among healthy elderly men. *J Hum Kinet, 28*, 15-23. doi: 10.2478/v10078-011-0018-9

Ray, C. T., Horvat, M., Croce, R., Mason, R. C., & Wolf, S. L. (2008). The impact of vision loss on postural stability and balance strategies in individuals with profound vision loss. *Gait Posture, 28*(1), 58-61. doi: 10.1016/j.gaitpost.2007.09.010

Redfern, M. S., Talkowski, M. E., Jennings, J. R., & Furman, J. M. (2004). Cognitive influences in postural control of patients with unilateral vestibular loss. *Gait Posture, 19*(2), 105-114. doi: 10.1016/S0966-6362(03)00032-8

Riley, M. A., & Clark, S. (2003). Recurrence analysis of human postural sway during the sensory organization test. *Neurosci Lett, 342*(1-2), 45-48.

Rine, R. M., Schubert, M. C., Whitney, S. L., Roberts, D., Redfern, M. S., Musolino, M. C., . . . Slotkin, J. (2013). Vestibular function assessment using the NIH Toolbox. *Neurology, 80*(11 Suppl 3), S25-31. doi: 10.1212/WNL.0b013e3182872c6a

Ring, C., Nayak, U. S., & Isaacs, B. (1989). The effect of visual deprivation and proprioceptive change on postural sway in healthy adults. *J Am Geriatr Soc, 37*(8), 745-749.

Robertson, R. J., Goss, F. L., Dube, J., Rutkowski, J., Dupain, M., Brennan, C., & Andreacci, J. (2004). Validation of the adult OMNI scale of perceived exertion for cycle ergometer exercise. *Med Sci Sports Exerc, 36*(1), 102-108. doi: 10.1249/01.MSS.0000106169.35222.8B

Robertson, R. J., Goss, F. L., Rutkowski, J., Lenz, B., Dixon, C., Timmer, J., . . . Andreacci, J. (2003). Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Med Sci Sports Exerc, 35*(2), 333-341. doi: 10.1249/01.MSS.0000048831.15016.2A

Rogind, H., Lykkegaard, J. J., Bliddal, H., & Danneskiold-Samsoe, B. (2003). Postural sway in normal subjects aged 20-70 years. *Clin Physiol Funct Imaging, 23*(3), 171-176.

Rosenhall, U. (1973). Degenerative patterns in the aging human vestibular neuro-epithelia. *Acta Otolaryngol, 76*(2), 208-220.

Rosenhall, U., & Rubin, W. (1975). Degenerative changes in the human vestibular sensory epithelia. *Acta Otolaryngol, 79*(1-2), 67-80.

Rossi-Izquierdo M, S.-P. S., Soto-Varela A. (2011). What is the most effective vestibular rehabilitation technique in patients with unilateral peripheral vestibular disorders? *Eur Arch Otorhinolaryngol*, *268*(11).

Rowell, L. B., Shepherd, J. T., & American Physiological Society. (1996). *Exercise : regulation and integration of multiple systems*. New York: Published for the American Physiological Society by Oxford University Press.

Rowell, L. B., Shepherd, J. T., & American Physiological Society (1887-). (1996). *Exercise : regulation and integration of multiple systems*. New York: Published for the American Physiological Society by Oxford University Press.

Rubenstein, L. Z., Robbins, A. S., Schulman, B. L., Rosado, J., Osterweil, D., & Josephson, K. R. (1988). Falls and instability in the elderly. *J Am Geriatr Soc, 36*(3), 266-278.

Ruhe, A., Fejer, R., & Walker, B. (2010). The test-retest reliability of centre of pressure measures in bipedal static task conditions--a systematic review of the literature. *Gait Posture, 32*(4), 436-445. doi: 10.1016/j.gaitpost.2010.09.012

Schubert, M. C., Tusa, R. J., Grine, L. E., & Herdman, S. J. (2004). Optimizing the sensitivity of the head thrust test for identifying vestibular hypofunction. *Phys Ther, 84*(2), 151-158.

Schwenk, M., Grewal, G. S., Honarvar, B., Schwenk, S., Mohler, J., Khalsa, D. S., & Najafi, B. (2014). Interactive balance training integrating sensor-based visual feedback of movement performance: a pilot study in older adults. *J Neuroeng Rehabil, 11*, 164. doi: 10.1186/1743-0003-11-164

Scott, J. C. (1990). Osteoporosis and hip fractures. *Rheum Dis Clin North Am, 16*(3), 717-740.

Serrador, J. M., Lipsitz, L. A., Gopalakrishnan, G. S., Black, F. O., & Wood, S. J. (2009). Loss of otolith function with age is associated with increased postural sway measures. *Neurosci Lett, 465*(1), 10-15. doi: 10.1016/j.neulet.2009.08.057

Shaffer, S. W., & Harrison, A. L. (2007). Aging of the somatosensory system: a translational perspective. *Phys Ther, 87*(2), 193-207. doi: 10.2522/ptj.20060083

Sheldon, J. H. (1963). The effect of age on the control of sway. *Gerontol Clin (Basel), 5*, 129-138.

Shepard, N. T., & Telian, S. A. (1995). Programmatic vestibular rehabilitation. *Otolaryngol Head Neck Surg, 112*(1), 173-182.

Shprecher, D., Schwalb, J., & Kurlan, R. (2008). Normal pressure hydrocephalus: diagnosis and treatment. *Curr Neurol Neurosci Rep, 8*(5), 371-376.

Shumway-Cook, A., Anson, D., & Haller, S. (1988). Postural sway biofeedback: its effect on reestablishing stance stability in hemiplegic patients. *Arch Phys Med Rehabil, 69*(6), 395-400.

Sidak, Z. K. (1967). Rectangular Confidence Regions for the Means of Multivariate Normal Distributions. *Journal of the American Statistical Association, 62*(318), 8.

Sienko, K. H., Balkwill, M. D., Oddsson, L. I., & Wall, C. (2008). Effects of multi-directional vibrotactile feedback on vestibular-deficient postural performance during continuous multi-directional support surface perturbations. *J Vestib Res, 18*(5-6), 273-285.

Sienko, K. H., Balkwill, M. D., Oddsson, L. I., & Wall, C., 3rd. (2013). The effect of vibrotactile feedback on postural sway during locomotor activities. *J Neuroeng Rehabil, 10*, 93. doi: 10.1186/1743-0003-10-93

Sienko, K. H., Vichare, V. V., Balkwill, M. D., & Wall, C., 3rd. (2010). Assessment of vibrotactile feedback on postural stability during pseudorandom multidirectional platform motion. *IEEE Trans Biomed Eng, 57*(4), 944-952. doi: 10.1109/TBME.2009.2036833

Sim, J., & Wright, C. C. (2005). The kappa statistic in reliability studies: use, interpretation, and sample size requirements. *Phys Ther, 85*(3), 257-268.

Sixt, E., & Landahl, S. (1987). Postural disturbances in a 75-year-old population: I. Prevalence and functional consequences. *Age Ageing, 16*(6), 393-398.

Stalenhoef, P. A., Diederiks, J. P., Knottnerus, J. A., Kester, A. D., & Crebolder, H. F. (2002). A risk model for the prediction of recurrent falls in community-dwelling elderly: a prospective cohort study. *J Clin Epidemiol, 55*(11), 1088-1094.

Steffen, T. M., Hacker, T. A., & Mollinger, L. (2002). Age- and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds. *Phys Ther, 82*(2), 128-137.

Stevens, J. A., Corso, P. S., Finkelstein, E. A., & Miller, T. R. (2006a). The costs of fatal and non-fatal falls among older adults. *Inj Prev, 12*(5), 290-295. doi: 10.1136/ip.2005.011015

Stevens, J. A., Corso, P. S., Finkelstein, E. A., & Miller, T. R. (2006b). The costs of fatal and nonfatal falls among older adults. *Injury Prevention, 12*(290).

Sullivan, E. V., Rose, J., Rohlfing, T., & Pfefferbaum, A. (2009). Postural sway reduction in aging men and women: relation to brain structure, cognitive status, and stabilizing factors. *Neurobiol Aging, 30*(5), 793-807. doi: 10.1016/j.neurobiolaging.2007.08.021

Swanenburg, J., de Bruin, E. D., Favero, K., Uebelhart, D., & Mulder, T. (2008). The reliability of postural balance measures in single and dual tasking in elderly fallers and non-fallers. *BMC Musculoskelet Disord, 9*, 162. doi: 10.1186/1471-2474-9-162

Tell, G. S., Lefkowitz, D. S., Diehr, P., & Elster, A. D. (1998). Relationship between balance and abnormalities in cerebral magnetic resonance imaging in older adults. *Arch Neurol, 55*(1), 73-79.

Tinetti, M. E., Doucette, J., Claus, E., & Marottoli, R. (1995). Risk factors for serious injury during falls by older persons in the community. *J Am Geriatr Soc, 43*(11), 1214-1221.

Tinetti, M. E., Mendes de Leon, C. F., Doucette, J. T., & Baker, D. I. (1994). Fear of falling and fall-related efficacy in relationship to functioning among community-living elders. *J Gerontol, 49*(3), M140-147.

Tinetti, M. E., Speechley, M., & Ginter, S. F. (1988). Risk factors for falls among elderly persons living in the community. *N Engl J Med, 319*(26), 1701-1707. doi: 10.1056/NEJM198812293192604

Tinetti, M. E., & Williams, C. S. (1998). The effect of falls and fall injuries on functioning in community-dwelling older persons. *J Gerontol A Biol Sci Med Sci, 53*(2), M112-119.

Tjernstrom, F., Fransson, P. A., Hafstrom, A., & Magnusson, M. (2002). Adaptation of postural control to perturbations--a process that initiates long-term motor memory. *Gait Posture, 15*(1), 75-82.

Toupet, M., Ferrary, E., & Grayeli, A. B. (2011). Visual analog scale to assess vertigo and dizziness after repositioning maneuvers for benign paroxysmal positional vertigo. *J Vestib Res, 21*(4), 235-241. doi: 10.3233/VES-2011-0420

Utter, A. C., Robertson, R. J., Green, J. M., Suminski, R. R., McAnulty, S. R., & Nieman, D. C. (2004). Validation of the Adult OMNI Scale of perceived exertion for walking/running exercise. *Med Sci Sports Exerc, 36*(10), 1776-1780.

Vandervoort, A. A., & McComas, A. J. (1986). Contractile changes in opposing muscles of the human ankle joint with aging. *J Appl Physiol (1985), 61*(1), 361-367.

Vereeck, L., Wuyts, F. L., Truijen, S., De Valck, C., & Van de Heyning, P. H. (2008). The effect of early customized vestibular rehabilitation on balance after acoustic neuroma resection. *Clin Rehabil, 22*(8), 698-713. doi: 10.1177/0269215508089066

Victoria Hornyak, J. M. V., Jennifer S. Brach. (2012). Measurement of Gait Speed. *Topics in Geriatric Rehabilitation, 28*(1), 6.

Viera, A. J., & Garrett, J. M. (2005). Understanding interobserver agreement: the kappa statistic. *Fam Med, 37*(5), 360-363.

Walker, M. L., Austin, A. G., Banke, G. M., Foxx, S. R., Gaetano, L., Gardner, L. A., . . . Penn, L. (2007). Reference group data for the functional gait assessment. *Phys Ther, 87*(11), 1468-1477. doi: 10.2522/ptj.20060344

Wall, C., 3rd. (2010). Application of vibrotactile feedback of body motion to improve rehabilitation in individuals with imbalance. *J Neurol Phys Ther, 34*(2), 98-104. doi: 10.1097/NPT.0b013e3181dde6f0

Wall, C., 3rd, & Kentala, E. (2005). Control of sway using vibrotactile feedback of body tilt in patients with moderate and severe postural control deficits. *J Vestib Res, 15*(5-6), 313-325.

Wall, C., 3rd, Weinberg, M. S., Schmidt, P. B., & Krebs, D. E. (2001). Balance prosthesis based on micromechanical sensors using vibrotactile feedback of tilt. *IEEE Trans Biomed Eng, 48*(10), 1153-1161. doi: 10.1109/10.951518

Wall, C., 3rd, Wrisley, D. M., & Statler, K. D. (2009). Vibrotactile tilt feedback improves dynamic gait index: a fall risk indicator in older adults. *Gait Posture, 30*(1), 16-21. doi: 10.1016/j.gaitpost.2009.02.019

Whipple, R. H., Wolfson, L. I., & Amerman, P. M. (1987). The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. *J Am Geriatr Soc, 35*(1), 13-20.

Whitney, S. L., Roche, J. L., Marchetti, G. F., Lin, C. C., Steed, D. P., Furman, G. R., . . . Redfern, M. S. (2011). A comparison of accelerometry and center of pressure measures during computerized dynamic posturography: a measure of balance. *Gait Posture, 33*(4), 594-599. doi: 10.1016/j.gaitpost.2011.01.015

Whitney, S. L., & Sparto, P. J. (2011). Principles of vestibular physical therapy rehabilitation. *NeuroRehabilitation, 29*(2), 157-166. doi: 10.3233/NRE-2011-0690

Whitney, S. L., Sparto, P. J., Hodges, L. F., Babu, S. V., Furman, J. M., & Redfern, M. S. (2006). Responses to a virtual reality grocery store in persons with and without vestibular dysfunction. *Cyberpsychol Behav, 9*(2), 152-156. doi: 10.1089/cpb.2006.9.152

Whitney, S. L., Wrisley, D. M., Brown, K. E., & Furman, J. M. (2004). Is perception of handicap related to functional performance in persons with vestibular dysfunction? *Otol Neurotol, 25*(2), 139-143.

WHO. (2007). WHO Global Report on Falls Prevention in Older Age.

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait Posture, 3*(4), 12.

Winter, D. A. (2009). *BIOMECHANICS AND MOTOR CONTROL OF HUMAN MOVEMENT* (4th ed.): JOHN WILEY & SONS, INC.

Woollacott, M. H., Shumway-Cook, A., & Nashner, L. M. (1986). Aging and posture control: changes in sensory organization and muscular coordination. *Int J Aging Hum Dev, 23*(2), 97-114.

World-Health-Organization. (2003). Consultation on development of standards for characterization of vision loss and visual functioning. *WHO/PBL, 03*(91).

Wrisley, D. M., & Kumar, N. A. (2010). Functional gait assessment: concurrent, discriminative, and predictive validity in community-dwelling older adults. *Phys Ther, 90*(5), 761-773. doi: 10.2522/ptj.20090069

Wrisley, D. M., Marchetti, G. F., Kuharsky, D. K., & Whitney, S. L. (2004). Reliability, internal consistency, and validity of data obtained with the functional gait assessment. *Phys Ther, 84*(10), 906-918.

Yardley, L., Donovan-Hall, M., Smith, H. E., Walsh, B. M., Mullee, M., & Bronstein, A. M. (2004). Effectiveness of primary care-based vestibular rehabilitation for chronic dizziness. *Ann Intern Med, 141*(8), 598-605.

Yardley, L., Gardner, M., Bronstein, A., Davies, R., Buckwell, D., & Luxon, L. (2001). Interference between postural control and mental task performance in patients with vestibular disorder and healthy controls. *J Neurol Neurosurg Psychiatry, 71*(1), 48-52.