Reliability and Validity of Electronic Measures of Balance and Gaze Control in People with Peripheral Vestibular Hypofunction

by

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Abstract

The purpose of this study was to assess the reliability and validity of a new computerized method of assessing balance and gaze control under a broad range of physical and visual conditions in people with vestibular hypofunction. Test retest reliability for balance performance as measured by COP excursion was good in all conditions with ICCs ranging from .64 to .90 in the AP and ML directions. Closed loop visual tracking as measured by COD had high reliability on the sponge and treadmill (ICC=.71-.75) as compared to open loop tracking (ICC=.325-.463) which was poor. Convergent validity showed poor correlation between clinical tests and the electronic balance and gaze assessments. Construct validity demonstrated that as physical and visual loads increased, balance performance decreased significantly on the sponge as measured by an increase in COP excursion and visual tracking performance decreased significantly on the treadmill as measured by a decrease in COD.

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Abbreviations

AP	Anterior-Posterior
aVOR	Angular Vestibular Ocular Reflex
BOS	Base of Support
BPPV	Benign Paroxysmal Positional Vertigo
cDVA	Computerized Dynamic Visual Acuity
CI	Confidence Interval
CL	Closed Loop (with respect to the head)
CNS	Central Nervous System
CO2	Carbon Dioxide
COD	Coefficient of Determination
COM	Centre of Mass
COP	Centre of Foot Pressure
CTSIB	Clinical Test of Sensory Interaction on Balance
DBA	Dynamic Balance Assessment

df	Degrees of Freedom
DGI	Dynamic Gait Index
DHI	Dizziness Handicap Inventory
DVA	Dynamic Visual Acuity
ETDRS	Early Treatment Diabetic Retinopathy Study
EMG	Electromyography
ENG	Electronystagmography
FSA	Force Sensor Array
GST	Gaze Stabilization Test
ICC	Intraclass Correlation Coefficient
ICF	International Classification of Functioning
LOB	Loss of Balance
mCTSIB	modified Clinical Test of Sensory Interaction on Balance
MRI	Magnetic Resonance Imaging
MS	Multiple Sclerosis
OKN	Optokinetic Nystagmus

OKR	Optokinetic Reflex
OL	Open Loop (with respect to head)
PICA	Posterior Inferior Cerebellar Artery
PVD	Peripheral Vestibular |Disease
SCC	Semi-Circular Canal
SCM	Sternocleidomastoid
SD	Standard Deviation
SEM	Standard Error of Measurement
SPEM	Smooth pursuit eye movements
SOT	Sensory Organization Test
SPL	Sway Path Length
SVA	Static Visual Acuity
tDHI	total Dizziness Handicap Inventory
tVOR	translational Vestibular Ocular Reflex
VBI	Vertebral Basilar Insufficiency
VOR	Vestibular Ocular Reflex

Chapter 1. Introduction:

The vestibular system plays an important role in the day to day maintenance and recovery of balance. It provides us with information about self motion, orientation in space and coordination of eye-head movements. The information it generates from specialized sensory receptors is used by the central nervous system to help with balance and gaze stability. Damage to the vestibular system through disease or trauma can cause changes to a person's function and participation, which, as defined by the International Classification of Functioning, Disability and Health means the ability to be "involve(d) in a life situation". Rehabilitation needs to address the assessment and treatment of the whole person including physical, physiological and psychological functioning in order to maximize active participation within the environment (World Health Organization, 2002).

Clinicians traditionally incorporate a variety of diagnostic and evaluative tools into their assessment in order to measure and record balance, gaze stability, orientation, dizziness and the impact of the disability on individual lives. Examples of such tests include static balance tests, the dynamic gait index (DGI), the dynamic visual acuity test (DVA) and the dizziness handicap inventory (DHI). These tests are valuable in providing a baseline for future reference and change over time but little is known about the strength of the correlation between the DHI, the clinical tests and measures of balance.

There is a need for the development of uniform outcome measures that are both quantitative and objective and can be used with people who have dizziness and imbalance secondary to vestibular dysfunction. These measures are needed to provide information about diagnosis and treatment planning and can be used together with instruments such as the DHI that measure perception of health and disability. This will assist in determining what interventions are needed to bring about improvements in one's sense of physical wellbeing. This is a challenge for rehabilitation.

Objective evaluation can be carried out using electronic computer-based measures. These performance-based measures can be used to not only evaluate impairment, but to also evaluate tasks that are functionally relevant to the person. Examples of this would include how and to what extent walking (activity) is affected by dizziness and the ability to regain balance after an unexpected perturbation (body function and structure). Someone's perception of their own dizziness or imbalance is an example of how their past and present experiences and coping strategies influence their ability to participate in activities such as shopping, working or socializing with friends (participation).

The purpose of the proposed study will be to evaluate a new method of assessment using performance-based electronic measures of balance and gaze control for use in daily clinical practice. Together with a questionnaire that measures perception of dizziness, we can identify appropriate physiotherapy interventions that are realistic and follow best practice guidelines.

Chapter 2. Literature Review:

2.1 Function of vestibular sensory organs

The vestibular system in humans has three important functions:

a) It is important in maintaining balance and restoring balance.

b) It helps maintain gaze control or eye-head coordination to maintain image stability.

c) It is important in the perception of body movement and head position relative to the environment and to gravity (Horak, Shupert, Dietz, & Horstmann, 1994).

Vestibular, visual and somatosensory systems all contribute to providing an internal frame of reference for body segment orientation and an external frame of reference for spatial orientation, namely vertical and support surfaces. The vestibular system, in particular the otolith end-organs, is the only sense organ that can provide an absolute external reference frame with respect to gravity. Rehabilitation after the loss of vestibular function requires inputs from multiple sources. It requires exposure to visual inputs, head motion and whole body movements. It should employ activities that a person is familiar with and that are also motivating and engaging (Rob Creath, Kiemel, Horak, & Jeka, 2002; Peterka, 2002).

The following sections will discuss the structure of the vestibular system, reflexes, pathology and diagnostics, balance control, gaze control and the functional and perceptual problems associated with vestibular disease and injury.

2.2 Structure of the Peripheral Vestibular System

The following is an overview of the peripheral vestibular apparatus. A more detailed description of the anatomy and physiology of the peripheral vestibular system can be found in Hain & Helminski (2007) and Kandel, Schwartz, & Jessel (1991).

The vestibular sense organs are comprised of a set of three semi-circular canals: horizontal, anterior and posterior and two otoliths, the saccule and utricle which are situated in inner ear or labyrinth. These specialized motion receptors function to provide an absolute frame of reference with respect to gravity and body orientation in space. They sense both linear head movement and angular acceleration required for eye-head coordination and gaze stability and provide valuable information regarding self motion. As well, they help in orientating the head and body to vertical. Injury to this important system produces a range of symptoms that include imbalance, difficulty with gaze control, and problems with eye-head coordination that can cause vertigo, dizziness, oscillopsia, nausea and motion sickness (Mandalà & Nuti, 2009; Sloane, Coeytaux, Beck, & Dallara, 2001).

Semi Circular Canals

The semi-circular canals (SCCs) are located in the inner ear within the petrous portion of the temporal bone. They function as sensory receptors and are responsible for detecting rotational or angular motion of the head. The 3 pairs of semi-circular canals are arranged perpendicularly to each other in an orthogonal manner similar to the arrangement of two walls and the ceiling of a room. They are thus able to detect motion in all three planes of movement. Each SCC is paired with a corresponding SCC in the opposite ear. The arrangement of paired coplanar canals in the right and left ear correspond very closely to each other and to the planes of the muscles of the eyes. Their perpendicular arrangement and pairing with the canals of the opposite ear results in a push-pull relationship. The semi-circular canals are comprised of a bony labyrinth containing perilymphatic fluid made up of sodium and potassium ions. Suspended within the bony labyrinth is the membranous labyrinth containing endolymphatic fluid. Each canal has an ampulla, or a widening of the canal just before it enters the utricle. The semi-circular canals are partitioned off in the ampulla by the cupula which is a flexible membrane spanning the width of the canal. The hair cells of the ampulla rest on the crista ampularis. This structure contains nerve fibers, blood vessels and supporting cells. Each hair cell is innervated by a vestibular ganglion cell in Scarpa's Ganglion. The hair cells act as sensory transducers when bent. Passive and active movements of the head in an angular direction cause the fluid to move and exert force on the cupula which results in the bending of the hair cells. The bending of the hair cells causes electrical impulses to be generated in the nerves causing either excitation or inhibition of a membrane potential depending on the direction of the movement. These signals are recorded by the vestibular nerves and transmitted to the brainstem for further processing (Hain & Helminski, 2007; Kandel et al., 1991).

When the canals are at rest, they have a tonic firing rate of 80 to 100 pulses per second and are always active. This tonic firing rate can be modified up or down depending on the head motion. When the head moves in one direction, one side is inhibited while the other side is excited in a push-pull relationship. The benefit of this arrangement is that if one canal is damaged, the other canal can still provide information to the central nervous system (CNS) about the movement (Kelly, 1991). Once the side that is being inhibited reaches 0 pulses per second, the other side will continue to fire at a rate that is unopposed by the opposite side. This asymmetry means that even at angular head movements of over 200 deg/second rotation, the excitatory response to rotation of a canal is greater than the inhibitory response of a canal. This inability to inhibit the firing of the vestibular nerve to rates of less than 0 in order to cancel out the excitatory stimulation, known as Ewald's second law, provides an explanation as to why patients with vestibular dysfunction tend to avoid movement toward the affected side (Hain & Helminski, 2007; Leigh & Zee, 1999).

SCCs are very sensitive to motion and can detect angular accelerations and decelerations of amplitudes as small as $0.1°/sec^2$. They sense angular motion and head velocity. During angular head motion, the vestibular ocular reflex (VOR) is produced which results in compensatory eye movements needed to maintain stable gaze during head motion and to prevent blurring of vision. As the head moves, there is acceleration of the fluid in the semi-circular canals causing a drag and a resultant bending of the hair cells in the cupula. Depending on which direction the head is moving, hair cells will be bent toward the kinocillium, a specialized hair cell that provides an axis about which the other hair cells are organized around the striola. Tilting of the head, regardless of the direction of movement will result in some cells being hyperpolarized and others being depolarized, sending information to the brain about position of the head in space (Kelly, 1991).

Otoliths:

The two otolith end-organs, called the utricle and saccule, are contained within the vestibule of the inner ear. This structure is bathed in endolymphatic fluid which helps to support and suspend these structures in position. The function of the otoliths is to sense linear movement in three directions and to provide information about head position and head tilt with respect to gravity.

The sensory transducers or hair cells of the utricle and the saccule arise from a thickened portion of the epithelium called the macula. The hair cells are comprised of multiple stereocilia and a single kinocilium which are embedded in a matrix of gelatinous material on top of which sits the otoconia or calcium carbonate crystals. When the head moves, the endolymph moves causing the stereocilia to become displaced or bent. If the stereocilia are moved toward the kinocilium, the hair cells are excited. When the hair cells move away from the kinocilium, they are inhibited. Linear movement of the head that occurs when going in an upward, downward or sideways direction or when the head is tilted causes gravity to pull the otoconia toward the earth resulting in bending of the hairs. These sensory receptors cells become excited and an action potential is generated.

The utricle lies in a horizontal plane when the head is vertical. It is oriented in such a way that it detects lateral accelerations of the head as well as posterior-anterior accelerations, along the horizontal plane. The saccule is oriented vertically and responds to vertical movements.

The direction that the head moves influences which nerve endings are stimulated. The primary purpose of the SCCs and otoliths is to sense angular and linear acceleration and head position relative to gravity. They play a major role in gaze, orientation in space and balance (Kelly, 1991).

2.3 Gaze Control:

Gaze stability is important in daily functioning and required for the maintenance of clear vision. Gaze control and eye-head coordination function to maintain visual fixation of objects of interest on the fovea of the retina during movements of the object, the environment and the head. Stabilizing the visual image on the fovea of the retina is required for accurate processing of visual information. The vestibular system plays an important role in the maintenance of balance and in stabilizing images on the fovea of the retina during head motion (Land 2006). The fovea represents less than 1% of the total area of the retina and is highly specialized for visual acuity. Anatomically however, it is represented by a large area on the visual cortex. The fovea is highly concentrated with cone photoreceptors that are tightly packed together. The density of the cones decreases as you move away from the centre of the fovea. They are replaced by rods towards the periphery of the retina. It is on the fovea where high spatial resolution and visual acuity occur. Deficits in the ability to stabilize gaze while the head and target of interest are moving result in the perception of self motion or environmental motion. Patients with vestibular deficits may have the sense that the environment is moving. These inaccurate motion signals result in loss of balance. Other symptoms include blurred vision, oscillopsia, nausea vertigo and falls (Land, 2006; Lord & Menz, 2000; Smart, Stoffregen, & Bardy, 2002; Tinetti & Williams, 1998). To obtain maximal gaze stability and visual acuity, the image or object of interest needs to be maintained on the fovea of the retina during motion of the head and body and the amount of retinal image slip must be minimized (Angelaki, Zhou, & Wei, 2003; Schubert & Minor, 2004).

Gaze control during body and head movement requires a coordinated combination of eye movements. There are five main classifications of eye movements which contribute to the maintenance of visual processing and gaze stabilization. The first two systems are the vestibulo-ocular and optokinetic reflex systems which work together to help stabilize the eye and prevent slippage of the image off the fovea when the head is moving thus enabling clear vision. The next three include smooth pursuit, saccades and vergence. They function to maintain foveation on the object of interest. These movements are voluntary and require that attention be paid to the target (Lambert, Sigrist, Delaspre, Pelizzone, & Guyot, 2010).

2.3.1Eye Movements

Vestibular Ocular Reflex (VOR):

The angular VOR (aVOR) is a very fast acting disynaptic reflex arc with a latency of less than 15 ms that rotates the eyes very quickly in order to compensate for head motion. It assists in minimizing retinal image slip on the fovea while fixating on a moving object. As the head rotates, the SCCs are activated providing the signal to the brainstem about how much the head is moving which in turn transforms that signal into an eye movement of an equal and opposite direction.

To maintain foveation or visual fixation of a target of interest on the retina, the gain or coordination of eye movements to head movements must be close to one or unity. If this is not accomplished, there will be retinal image slippage and blurring. Long term adaptation can cause the gain of the VOR to change. This reflex functions during brief and rapid head movements of 2 Hz or more. During slow tracking or sustained head movements below 100°/s, the velocity storage system can to assist the VOR and help facilitate the process of transitioning from the VOR to the optokinetic reflex system (Goldberg, Eggers, & Gouras, 1991; Hain & Helminski 2007; Kelly, 1991).

The aVOR is driven by the activation of the SCCs of the inner ear. Hair cells in the SCCs are stimulated during angular head rotation. A main afferent projection from the SCCs goes to the medial and lateral vestibular nuclei. These vestibular nuclei in turn project to the alpha motor neurons of the oculomotor muscles that control the movements of the eyeball. A deficient aVOR from damage to the vestibular nerve or SCCs will result in a decreased gain resulting in slippage of the image off the fovea of the retina and blurring of vision during visual fixation and active head movement. Compensatory eye movements that are necessary to stabilize images on the fovea become decreased and inaccurate. Images that are not clearly represented on the fovea become unstable and blurry. Gaze control is lost and disorientation can occur. People with vestibular dysfunction have problems stabilizing gaze and keeping objects within their environment steady. The resulting dizziness leads to changes in balance (Goldberg et al., 1991; Hain & Helminski, 2007).

Another reflex, the translational VOR (tVOR), plays a role in minimizing retinal slip and maintaining visual acuity in binocular gaze during forward translation as experienced while walking forward or moving in a car. Linear motion of the body in vertical, lateral or forward directions combines both head and eye rotations (Demer & Viirre, 1996; Wei & Angelaki, 2004). Gaze stability during linear motion is felt to be maintained by naturally occurring head rotation in combination with rotation of the eyes. The tVOR receives its inputs from both the otoliths and the SCCs. The gain of the tVOR is adjusted inversely according to the viewing distance. Its responsivity increases significantly at near viewing and declines during monocular viewing (Liao, Walker, Joshi, Reschke, & Leigh, 2008). The tVOR is less responsive during far viewing because it does not produce retinal slip (Angelaki, 2004). It is also felt to be closely coupled to foveal vision and stereopsis because during movement, the eyes adjust their position three dimensionally according to the geometrical demands required to maintain foveal acuity (Angelaki et al., 2003).

Optokinetic Reflex System:

The optokinetic reflex (OKR) complements the VOR. Together, they stabilize the image on the retina while the head is moving at various speeds. Optokinetic inputs are visually driven and are stimulated by the movement of large visual backgrounds across the periphery of the retina. The velocity of the visual image moving across the retina is used to determine the velocity of the head as it is moving. Through this visual mechanism, compensatory eye movements are generated during head motion in a manner similar to that of the VOR. The optokinetic system provides the head motion signal which is the estimate used to drive the eyes in the opposite direction. The optokinetic system, like the VOR system, works to determine the direction, speed and amount of head movement. These two involuntary systems have very short latencies and operate together to produce eye movements to fully compensate for head movements and to present retinal image slip of the foreground image on the fovea during foveation (Goldberg, Eggers, & Gouras, 1991).

Smooth Pursuit Eye Movements (SPEM):

We track moving objects in our environment using smooth pursuit eye movements. These slow tracking movements function to stabilize small moving targets on the fovea at lower velocities of about 15°/sec to 30°/sec at maximum (Land, 2006). The smooth pursuit system is a voluntary function and helps to maintain visual fixation on moving targets when the head is still as well as when it is moving. The speed of SPEM are determined by the velocity of the moving target. SPEM help to correct velocity errors (retinal slip) that occur between the eye and the target by determining target speed and adjusting the eyes accordingly. Smooth pursuit by itself is not fast enough to keep up with fast moving or unpredictably moving targets so it is supplemented by saccades (Orban de Xivry & Lefèvre, 2007). Smooth pursuit functions best at speeds of 1 Hz or less. It is processed in the frontal eye field of the visual cortex and brainstem nuclei (superior colliculus).

Saccades:

Saccades are rapid voluntary eye movements that bring targets of interest onto the fovea. They occur at very high velocities of up to 1000°/sec^{-1} with a very short duration of 30-80 ms. The speed of a saccade is determined by the distance to the target. If smooth pursuit lags behind the movement of the target, saccades help catch up to the target and are then called “catch-up saccades”. Another type of saccade toward a stationary target is simply called a saccade (Orban de Xivry & Lefèvre, 2007). Saccades are voluntary movements and are processed by the frontal eye fields, visual cortex and the parietal lobe.   They can be initiated by sound or tactile stimulation such as when you hear a noise or something touches you.

2.4. Balance and Orientation:

“Balance is a functional term”… and is defined as the ability to maintain and control the position and motion of the total centre of mass relative to the base of support (Betker, Szturm, & Moussavi, 2009). It is required at rest, in standing, during voluntary and predictable changes to posture that occur in walking, with turning or moving from one position to the next as well as during unpredictable changes in posture that occur during a sudden and unexpected perturbation (Maki & McIlroy, 1996). The maintenance of balance at rest and during a voluntary or preplanned motion uses a predictive or anticipatory control mechanism called feed-forward. Feed-forward control is necessary in maintaining balance during predictable movements as seen in cyclical trunk movements or while bending. Dietz, Trippel, Ibrahim, & Berger (1993) and Van Ooteghem, Frank, & Horak (2010) demonstrated that when the frequency or amplitude of a sinusoidally moving platform changed, so did the performance of the muscles and electromyography activity. Within a few cycles, the muscles were able to adapt and change their performance in anticipation of the change in amplitude and frequency and able to prepare for the next anticipated movement thereby showing a learning effect. Recovery of balance during unexpected postural perturbations and environmental conditions also requires a feedback system of control capable of responding rapidly to correct any sudden loss of balance.

The ability to sense when balance is at risk and to respond quickly and efficiently in a timely manner requires both feed forward and feedback control. The selection of the appropriate balance response depends on the degree of difficulty of the task and the physical demands of the environment such as lighting conditions or the characteristics of the support surface (i.e. slippery, soft, uneven etc.) (Horak, Nashner, & Diener, 1990; Jacobson, Newman, Hunter, & Gene, 1991; Loader et al., 2007; Szturm, Betker, Moussavi, Desai, & Goodman, 2011; Whipple, Wolfson, Derby, Singh, & Tobin, 1993).   Maintaining balance and orientation in space requires integration of multiple sources of sensory information: namely the visual, vestibular and somatosensory systems (Black, Wall, & Nashner, 1983; Shumway-Cook & Horak, 1986).

Each class of spatial sensory information is distinct and provides its own frame of reference regarding body segment motion and orientation relative to space. Balance requires both internal and external representations of body image to provide the necessary sensory information needed to detect orientation of the body with respect to gravity. Spatial orientation requires vestibular and visual inputs to determine where vertical and body position is relative to gravity. The otolith sense organs provide an invariant or fixed frame of reference (i.e. gravity vector) necessary to orientate the body and to help reconcile any sensory conflict situations that arise when visual or somatosensory inputs are absent or distorted (Kelly, 1991).

The balance control system, however, cannot rely on vestibular spatial information alone. It also requires an internal spatial reference frame which can only be provided by proprioceptors (i.e. muscle spindles and Golgi tendon organs). Vision provides an external frame of reference but this is not available in the dark. In addition, vision can only provide information of the relative motion between oneself and the environment(Kelly, 1991). This can result in sensory conflict situations and illusions which are capable of destabilizing balance making it difficult to distinguish between environmental or self motion. (Borel, Lopez, Péruch, & Lacour, 2008; Ghez, 1991) Optokinetic stimulation can impact balance and perception of orientation. For example, large field visual motion scenes and optokinetic stimulation have been shown to induce optokinetic nystagmus (OKN) and body sway in the direction of the slow phase of the nystagmus (Bronstein, 1995; Ohyama, Nishiike, Watanabe, Matsuoka, & Takeda, 2008; van Asten, Gielen, & van der Gon, 1988; Vitte, Sémont, & Berthoz, 1994). By using virtual environments and optokinetic stimulation, subjects were exposed to various moving scenes which produced disturbances and perceptions of self motion. The size of the visual field, the speed of the movement and the frequency of the patterns influenced the amount of body sway. Training using optokinetic stimulation has been shown to improve amplitude and symmetry between the two sides in unilateral lesions, decrease retinal slip, and to improve control of eye movements and optokinetic nystagmus in the opposite direction to the moving scene (Vitte et al., 1994).

Proprioceptors provide internal reference cues about kinesthetic sense. Muscle spindles determine muscle length and provide information about joint angular position and motion, whereas Golgi tendon organs determine muscle tension that occurs when muscles are stretched or contracted. These sensory receptors supply information about position and movement of individual body segments relative to each other, but do not reference vertical or the ground. Tactile and pressure sensors in the feet provide an external frame of reference for ground position, surface quality and pressure (Menz, Lord, & Fitzpatrick, 2006; Zupan et al., 2000).

Balance control during standing and walking integrates spatial information from these sensory systems. In situations where vestibular signals become decreased, in particular gravity sense, then other sources of spatial information with external frames of need to be recalibrated. Lacour, Dutheil, Tighilet, Lopez, & Borel (2009) studied strategies that humans used to recover post-operatively from a unilateral neurectomy. Patients used different strategies for balance control depending on their personal preference. Some patients preferred to use external frames of reference (allocentricity) to determine their subjective visual vertigo (SVV), while others depended less on external cues and used internal weighting of their SVV to help with balance (egocentricity). Recovery was improved for both groups in the light where external frames of reference could assist with cues about orientation in space.

Individual coping styles, past experiences and personal preferences need to be considered when assessing and developing treatment programs for patients.

Challenges to balance result when more than one of the three systems doesn't function accurately or the interaction between the three systems is altered. If one sensor becomes damaged or distorted, the other sensors become more dominant and the task of balancing becomes more difficult The CNS can assist with the recalibration and reorganization of the sensory information from these systems and helps with sensing any threat to balance (Zupan et al., 2000).

2.4.1 Sensory Organization Test:

Computerized dynamic posturography (Neurocom International, Inc.) and the Equitest (Black et al. 1983) used 6 different sensory conditions in a test called the sensory organization test (SOT) to determine how much each of these three classes of sensors: visual, somatosensory or vestibular contributed to balance control. The SOT measures changes in centre of foot pressure (COP) during quiet stance while sensory information is manipulated and can thus isolate specific signals coming from any one of the three systems. It is performed on a moveable platform that rotates around the axis of the ankle joint. The platform contains force plates with strain gauges that measure the centre of vertical foot pressure as the body sways over the feet under different balance conditions. Black et al. (1983) measured and recorded anterior-posterior (AP) postural sway relative to the ankles by using a potentiometer. The visual environment surrounding the platform was manipulated with a hydraulic servomechanism that moved the platform and the visual surround proportionately to the postural sway of the subject standing on it. In this way, normal sensory inputs from the ankles and from vision were disrupted by moving the platform, the visual surround or both simultaneously according to how much the subject swayed. When sensory information is manipulated in this manner, it becomes difficult to orient oneself to earth horizontal and vertical. This is referred to as sway referencing.

In the 1983 study, the COP of 12 subjects with vestibular loss and with 2 age-matched normals was measured. Six balance tests were performed and the sway was recorded on each subject under the following conditions:

1. Eyes open on a fixed surface: Somatosensory and visual systems provide inputs. All three sensory systems are available.

2. Eyes closed on a fixed surface: Visual signals eliminated. Vestibular and somatosensory inputs are available.

3. Fixed surface with visual surround that sways proportionately to body sway: In this condition the visual surround moves proportionately to body sway. There is no relative difference between body movement and visual surround. Visual information is distorted and sensory conflict situations contribute to the destabilization of balance. Vestibular and somatosensory information are present.

4. Sway referenced support surface (no ankle sensory inputs) with eyes open: In this condition, the support surface on which the person is standing moves in synchrony and proportionately with body sway, effectively cancelling out the

movement and somatosensory signals from the ankles. Somatosensory inputs from the ankles are eliminated or distorted. Only vestibular and visual inputs are available.

5. Sway referenced support surface with eyes closed: In this condition, the somatosensory inputs from the ankles are eliminated or distorted and vision is eliminated, leaving only vestibular inputs to reference balance.

6. Sway referenced support surface with conflicting visual inputs (visual surround moved proportionately to ankle sway): In this condition, the subject stands on a sway referenced platform with a sway referenced visual surround. Somatosensory inputs are eliminated or distorted, visual inputs are distorted, and the only sensory inputs available to sense balance are vestibular.

In conditions 1 to 3, where the support surface was fixed relative to earth horizontal, all subjects were able to orientate themselves vertically, similar to normals. In condition 4, the support surface was sway referenced making it difficult to derive somatosensory information from the ankles resulting in greater weighting of vestibular and visual inputs. In condition 5 when the eyes were closed and visual cues were absent while standing on the sway referenced platform, sway increased. Most subjects, except those with extensive vestibular damage, were able to maintain their balance in this condition, relying primarily on remaining vestibular function. In condition 6, where both ankle and visual inputs were eliminated or distorted, more sway was noted in all subjects and several lost their balance. Inaccurate visual and somatosensory information resulting from loss of relative motion signals between the ankles and the environment caused sensory conflict situations. Consequently, errors were made in sensing vertical and loss of balance occurred. Normal subjects and subjects with minor residual vestibular deficits were able to maintain their balance albeit with increased sway.

By eliminating or distorting one sense at a time, this study demonstrated how sensory inputs could be manipulated resulting in greater reliance on other senses. As the balance task became harder by the elimination or distortion of vision and alteration of somatosensory inputs, greater reliance was placed on vestibular inputs. As long as reliable inputs regarding earth vertical or earth horizontal were available, balance was maintained. However, as the balance tasks became harder and visual and somatosensory conflicts were introduced, there was a greater likelihood of balance loss and falls. Furthermore, subjects with greater vestibular loss had more difficulty in reorganizing distorted or absent sensory inputs and stabilizing themselves. Balance can be maintained if there is loss or distortion of only one of the sensory systems, but becomes challenged or impossible when more than one is absent or becomes unreliable.

Clinical tests of balance, including the DGI(Shumway-Cook, Gruber, Baldwin, & Liao, 1997; Whitney, Hudak, & Marchetti, 2000), Berg Balance Scale (Berg, Wood-Dauphinee, Williams, & Maki, 1992; Bogle Thorbahn & Newton, 1996; Shumway-Cook, Baldwin, Polissar, & Gruber, 1997; Whitney, Wrisley, & Furman, 2003) and the Timed Up and Go (Whitney, Marchetti, Schade, & Wrisley, 2004) are used to predict falls but by themselves are not sensitive to the underlying cause of the problem and detect small changes in balance. Cohen & Kimball (2008) demonstrated that when used in combination with other clinical assessments of balance, specifically the Functional Mobility Test which assesses avoidance of obstacles, the SOT was more sensitive to screening people who had vestibular dysfunction than clinical balance tests alone. Using the SOT along with other clinical tests of balance is useful as a screening tool for people who may need to have further diagnostic testing of vestibular function.

One problem with the SOT is that it is expensive, large, not portable and complicated to use. Shumway-Cook & Horak (1986) developed a simpler and less expensive version of the SOT. This test, called the Clinical Test of Sensory Interaction on Balance (CTSIB), is used to evaluate postural stability under 6 different conditions similar to the SOT, only instead of using a sway referenced platform, a sponge was used to distort the signals coming from the ground. The six conditions included standing on a firm surface or a sponge surface, eyes open or closed, with an altered visual conflict condition created by using a large dome worn by the subject on their head and altering the vertical frame of reference which distorted the visual cues with respect to earth vertical. This test has been called the “foam and dome test”. It is scored using a numeric ranking scale where 1= minimal sway, 2=mild sway, 3=moderate sway and 4=fall. As well, the amount of time maintaining balance was recorded and the amount of sway recorded by the use of grids or a plum line. The compliant sponge surface used in this test emulated the moving platform used in the SOT and altered somatosensory inputs, forcing greater reliance on the other systems for balance. Movements were not restricted to an AP direction but were multi-directional.

Compliant surfaces, such as a sponge, alter the balance adjustments and muscle forces required to maintain balance (Blackburn, 2003; Patel, Fransson, Lush, Peterson, Magnusson, Johansson, 2008). A sponge alters the ability to maintain stability in standing in all planes of movement and changes the ground reaction forces resulting in increased frequency and amplitude of body sway causing changes to the COP. Balance reactions on a compliant surface are unpredictable and require greater attention to vision and somatosensory inputs. Loss of balance can happen in any direction. Ongoing modifications to balance are required to keep from falling while on the sponge. The demands placed on maintaining balance control vary depending on the required task as well as the features of the support surface and the environment. The greater the requirements of the balance task being undertaken, the more difficulty there is in maintaining stability. Threats to balance including changes in the supporting surface and visual conditions need to be sensed by the individual and appropriate adjustments made in order to reduce the chances of falling.

Assessing what balance strategies are being utilized can be helpful in treating the problem and providing appropriate intervention to reduce this risk (Allum, Zamani, Adkin, & Ernst, 2002; Creath, Kiemel, Horak, Peterka, & Jeka, 2005; Vitte et al., 1994). The information derived from the CTSIB provides the therapist with information about which sensory system the patient is most reliant on. Since the visual and somatosensory information can be distorted or eliminated, the remaining vestibular inputs, which are fixed, become weighted more heavily. The harder the balance task is and the greater the visual conflict, the greater becomes the likelihood of losing one's balance and falling, especially in the case of vestibular dysfunction. The

CTSIB has been evaluated and its reliability tested(Cohen, Blatchly, & Gombash, 1993; Giray et al., 2009; Lafond, Corriveau, Hebert, & Prince, 2004). Cohen et al (1993) reported test retest reliability of the CTSIB to be excellent. Performance declined on the foam for the subjects with vestibular impairment and there was a significant drop with the eyes closed and under the visual conflict condition where the dome was worn to distort the visual cues.

The SOT and CTSIB have since been modified, eliminating the visual surround condition. The newer test, called the modified Clinical Test of Sensory Interaction on Balance (mCTSIB) looks at balance under 4 conditions instead of 6: standing eyes open and closed on a firm surface and standing eyes open and closed on a sponge surface. Simply stated, it represents the Romberg test done on a firm surface and a compliant surface. The mCTSIB is easy and inexpensive to reproduce within the clinical setting. It is a valuable test in assessing the contribution of the three main sensory systems used in balance. The vestibular system is fixed with respect to inertial-gravity forces. By systematically manipulating the somatosensory and visual inputs, either by eliminating or distorting them one at a time or simultaneously, the amount of weighting put on each system can be assessed. If only one of the three sensory inputs is removed or altered, the remaining systems help maintain balance but when both somatosensory and visual inputs are distorted or removed, there is a forced reliance on the vestibular inputs. When the vestibular system is damaged or absent there is an increase in body sway and a loss of balance. The information obtained from this test is important in that it aids the therapist in understanding the degree of vestibular loss, assesses the function of the vestibular system and contributes valuable information to the design and implementation of an appropriate treatment programs (Teasdale, Stelmach, & Breunig, 1991). The m(CTSIB) has been found to have good inter-rater reliability (Loughran, Gatehouse, Kishore, & Swan, 2006) and is a simple and cost effective tool for assessing balance (Desai, Szturm, Betker, & Goodman, 2010; Giray et al., 2009).

Betker, Szturm, & Moussavi (2005) found that the COP signals between the top and the bottom of the sponge are different and that the COP signals change as the forces are dispersed through the sponge. The sponge is an ideal method of causing random and unpredictable alterations in balance however the measurement of these forces using a force plate that is placed under the foam is inaccurate. Desai, Szturm, Betker, & Goodman (2010) used a Forced Sensor Array (FSA) pressure sensing mat on top of the sponge rather than under it to record the COP before the ground reaction forces on the compliant surface became dispersed and distorted. This measurement system was used to record and measure balance in their study of 72 community dwelling older adults using a new balance assessment tool called the Dynamic Balance Assessment (DBA). It is well documented that balance while standing on a foam increases balance demands (Allum et al., 2002; Betker, Moussavi, & Szturm, 2005; Cohen et al., 1993; Creath et al., 2005; Shumway-Cook & Horak, 1986) however the task of stationary standing still places only limited demands on balance and does not represent tasks typically performed in the activities of daily living. Desai et al. incorporated the mCTSIB into their study (eyes open and closed on a firm and sponge surface) with the added tasks of bending the trunk, lifting the arms, rotating the spine and moving the head from side to side. The inclusion of dynamic functional tasks in the assessment permitted stability to be examined under a broader range of tasks with different dynamic states and degrees of difficulty. COP position data was recorded using the FSA pressure sensing mat placed on top of both the firm and the foam surfaces and analyzed to determine the amount of body sway and balance costs of the task. The study was able to discriminate fallers from non-fallers who otherwise would not be identified by performance-based clinical assessment tests alone. The DBA is useful in assessing stability during functional tasks and dynamic balance controls which cannot always be determined during quiet standing on a solid surface. The study also showed that when two or more sensory inputs were either distorted or eliminated, it became significantly more difficult to maintain stability as evidenced by increased body sway and loss of balance. A similar assessment system has been developed for visual tracking tasks which can be performed in stance and during walking.

2.5 Pathology of the Vestibular System:

Damage or diseases of the vestibular system cause a range of distressing symptoms and functional problems for people ranging from loss of balance and dysequilibrium resulting in falls, difficulty with gaze control as well as nystagmus resulting in blurred vision. Other symptoms include motion sickness, disorientation, oscillopsia which is a sensation of unstable vision where the environment is perceived as moving back and forth, dizziness and vertigo. These problems can lead to a fear of falling, social isolation and anxiety. Under normal conditions, we are unaware of the influence that the vestibular system has on the functions of balance and mobility, but when injury or disease occur and cause a disruption to the integrity of the system, perceptual manifestations become evident. The burden of dizziness on the patient is great but often goes unmanaged. The cost to both the individual and the health care system can be substantial.

Common symptoms after peripheral vestibular disease (PVD) are dizziness and vertigo. Dizziness is a term used to describe a variety of different sensations ranging from light-headedness, presyncope, and imbalance to true rotational vertigo defined as a spinning sensation, either of self or the environment. The symptom of dizziness accounts for one of the top three complaints of people presenting to inpatient facilities (Kroenke, Stump, Clark, Callahan, & McDonald, 2011). A 2006 national health survey in Taiwan reported that within the Taiwanese adult population of 16,838,659 individuals, 527,807 people reported vertigo at least once during the year and the recurrence rate within the first year of their initial attack was 37.7% (Ying-Ta et al., 2011).

Dizziness can stem from multiple causes ranging from benign to serious. Very often, it is caused by problems within the vestibular system and its severity can range from mild to severe. Several subtypes have been described. Sloane et al divided it into four subheadings: vertigo, presyncopal lightheadedness, disequilibrium and other dizziness. Vertigo was defined as a spinning sensation of one’s self or of one’s environment. Presyncopal lightheadedness was defined as a feeling of near fainting or passing out lasting seconds to hours. Dysequilibrium was the sense of losing one’s balance, typically occurring while standing upright or walking. Other dizziness was harder to define, vague and often related more to dizziness arising from anxiety or other somatic or psychological problems (Sloane et al., 2001).

Frequently, these four subtypes of dizziness overlap making it hard to isolate a single factor as the primary cause. Generally in chronic cases, dizziness is not life-threatening, however in rare cases of acute vertigo it can be. More frequently, dizziness resulting from non-vestibular causes may be due to medications or metabolic reasons. Diagnosing and treating acute and chronic dizziness appropriately is a challenge for the clinician. Distinguishing between rare, life-threatening conditions and chronic, non life-threatening conditions can be difficult.

The disorientation and imbalance resulting from dizziness can place a great personal stress and a social burden on individuals due to difficulties with concentration and sensitivity to sounds, light and motion. Dizziness can negatively impact one’s quality of life and enjoyment of social activities and can lead to loss of employment, reduced capacity to perform activities of living such as driving and shopping, as well as social isolation. A functional approach to the assessment and treatment of dizziness in non life-threatening conditions has been suggested, including management of medications, treatment of underlying conditions, addressing problems related to gaze instability and exercises to improve strength, flexibility and balance. Understanding the type of dizziness that a patient is trying to describe and determining a pathophysical cause for it can guide the clinician in developing a plan of management.

The following section provides a brief overview of some of the more common types of disorders of the vestibular system. The types of pathology affecting the vestibular system have been organized into a section on Peripheral Vestibulopathy and Central disorders although some conditions, such as head injury overlap. Studies vary on the prevalence of each, but the prevalence of vestibular symptoms resulting from peripheral disorders ranges from 44% to 65% (Karatas, 2008) while the prevalence for central disorders is 25% (Baloh 1998). Next to age related hearing loss, known as presbycusis, Benign Paroxysmal Positional Vertigo (BPPV) is by far the most common inner ear disorder (Balatsouras et al., 2012; Yamasoba et al., 2013). Vertigo from BPPV is reported at 35% but will not be discussed in this paper as this syndrome is generally very responsive to one or two treatments of particle repositioning and does not result in long term or permanent changes to the vestibular system.

2.5.1 Peripheral Vestibular Disorders:

Neuronitis/Labyrinthitis

Baloh (2003) described vestibular neuritis as “an imbalance in tonic vestibular activity”. He explained that the main cause of peripheral disorders was usually a virus affecting the vestibular nerve, although it could also be caused by ischemia. Vestibular neuritis causes damage to the vestibular nerve and spares the hearing whereas a labyrinthitis generally involves some hearing loss. Frequently, these conditions are preceded by a viral infection of the upper respiratory tract. The virus attacks the hair cells in the inner ear resulting in a loss of signals from the vestibular system which reduces the activity of the VOR. How the viral process causes damage to the neuroepithelium is not clearly understood. When the normal symmetry of the

VOR between the two ears is disrupted, the intact side continues to fire as though it is being constantly stimulated thus creating the sense of ongoing movement. Damage to the vestibular apparatus can occur within any of the vestibular structures and cause any number of clinical signs and symptoms depending on where the lesion occurs. Nystagmus occurring from a peripheral lesion is usually in a horizontal direction except in benign paroxysmal positional vertigo (BPPV) where the nystagmus is a combined torsional upbeat or downbeat direction, depending on what canal is affected.

Horizontal nystagmus that beats towards the intact side is visible on examination during the acute stages. It is often accompanied by severe rotational vertigo, imbalance and intense nausea. A viral labyrinthitis or neuritis usually clears up in a few days, but symptoms of dizziness may persist for a long time afterwards depending on factors such as the extent of damage, co-morbidities, physical activity and age. Caloric testing reveals a vestibular hypofunction on the affected side. Recovery from a labyrinthitis or neuronitis and re-establishment of function happens in combination with central compensation of the tonic imbalance and physical activity through the process of adaptation. Appropriate exercises have been shown to improve balance, gaze stability and the gain of the vestibulo-ocular reflex (Szturm, Ireland, & Lessing-Turner, 1994).

Ototoxicity

Certain medications are toxic to the vestibular system. Ototoxicity will affect both ears resulting in bilateral vestibular loss. Two of the most ototoxic classes of drugs causing damage to the vestibular system are a) Aminoglycoside antibiotics which include Gentomicin and Streptomycin and b) Cisplatin which is a chemotherapeutic agent. Gentamicin enters the sensory hair cells of the vestibular system causing death to the cells and irreversible vestibular loss. Ototoxicity from Gentamicin use has been reported at 15% (Rybak & Ramkumar, 2007) and can also result in hearing loss (Chen et al., 2007). There is a limited dose response relationship between the degree of damage to the hair cell and the dose of the drug administered. The mechanism of damage is via free radical formation. It can stay in the inner ear for up to six months, making the ear more susceptible to injury if there has been a recent previous treatment (Dulon, Hiel, Aurousseau, Erre, & Aran, 1993). The damage may be more severe if used in combination with diuretics which by themselves can be ototoxic or in the elderly where there may already be fewer hair cells at the onset of treatment. There is also a familial component. The chemotherapeutic drugs Cisplatin and Carboplatin are also ototoxic and target the hair cells of the cochlea. The elderly and pediatric populations are particularly susceptible to the ototoxic effects of the drug. Investigations have shown that Cisplatin plays a role in vestibular toxicity (Kim et al., 2008; Reiter, Tan, & Korkmaz, 2011).

Other chemical agents that exert an influence on the vestibular system include aspirin, caffeine, alcohol, nicotine, recreational drugs and certain prescription drugs including anti-malarial drugs, sedatives and anti-inflammatory medication. Symptoms resulting from use of these drugs include tinnitus, changes to hearing, imbalance and dizziness. These may diminish over time if the exposure to the toxic agent is reduced or eliminated, depending on the level of exposure and amount of damage. If the exposure has resulted in irreversible damage, the symptoms may persist.

Disease:

The most common disease of the inner ear is Meniere’s disease. It is caused by malabsorption of the fluid of the semi-circular canals. It affects both the vestibular apparatus and the cochlea. Inadequate drainage of the endolymphatic fluid through the endolymphatic duct within the membranous labyrinth results in a buildup of pressure inside the ear resulting in dilatation and distention of the duct. This condition, called endolymphatic hydrops, is felt to be related to the development of Meniere’s disease. The cause of the drainage problem is not clear but may develop because of a blockage associated with changes in the anatomy of the temporal bone from trauma or due to congenital abnormalities. Other possible explanations postulated for the development of pressure in the ear include excessive production of endolymph by the striola vascularis, viral infections, allergies, abnormal immune responses, genetic predisposition, fibrosis or atrophy of the endolymphatic duct and sac, narrowing of the sac, otosclerosis of the vestibular aqueduct and vascular reasons to name a few (Merchant, Adams, & Nadol, 2005). A relationship appears to exist between hypodevelopment of the endolymphatatic duct and sac, constriction of the temporal bone and malabsorption of the endolymph. There is a positive relationship between hydrops and Meniere’s disease, but not everyone with hydrops will develop the symptoms of Meniere’s (Merchant et al., 2005).

Symptoms of Meniere’s include fluctuating hearing loss, aural fullness, tinnitus plus episodic, intense and incapacitating vertigo accompanied by nystagmus that can last anywhere from 30 minutes to hours and occasionally days. These intense and prolonged attacks of vertigo are felt to be due to episodic rupture of the membranous labyrinth and transient paralysis of the vestibular nerve. Recurrent attacks of Meniere’s disease gradually result in decreased hearing (confirmed on audiogram) and a vestibular hypofunction confirmed by reduced calorics on electronystagmography (ENG). The disease is frequently self-limiting over the course of 15 to 20 years during which time hearing and vestibular function becomes permanently damaged (Fetter, 2007).

Traditionally, physiotherapy in Meniere’s disease has been reserved for people who have had ablative medical management of the vestibular nerve or whose disease has stabilized. Dietary measures, including restriction of salt, are emphasized. Treatment consists of teaching substitution strategies, habituation exercises, balance exercises to improve balance and eye–head coordination and gaze stabilization exercises to drive recovery of the VOR. Recent evidence suggests that physiotherapy can also be helpful during the active phases of the disease in assisting with balance problems experienced between attacks (Gottshall, Topp, & Hoffer, 2010).

Other diseases or conditions affecting the vestibular system include but are not limited to otosclerosis, Cogans’s disease and Allports syndrome all of which can cause dizziness.

Superior canal dehiscence:

Superior semicircular canal dehiscence (Cox, Lee, Carey, & Minor, 2003) is diagnosed by high resolution CT scan of the temporal bone that is taken in a perpendicular and parallel plane to the superior SCC. With a superior SCC dehiscence, a hole is created in the roof of the canal secondary to head trauma or erosion of the bone. This opening results in contact with the dura, making it sensitive to pressure changes within the labyrinth. The primary complaint of patients with superior canal dehiscence is vertigo induced by pressure changes to the ear and/or sound (Tullio's phenomenon). Coughing, sneezing or nose blowing may cause vertigo. Autophony, that is, the ability to hear one's own voice or body sounds such as blinking, neck movements or chewing, is common. A conductive hearing loss is present. Treatment for this is surgical plugging of the canal (Minor, 2005). Physiotherapy post surgery involves balance retraining and reduction of symptoms of dizziness through eye-head coordination exercises and habituation exercises.

Perilymphatic Fistula:

Perilymphatic fistulas are rather rare and secondary to major trauma or significant changes in pressure (Friedland & Wackym, 1999). An opening at the site of the round or oval window, often caused by head trauma, barotrauma, a penetrating injury to the ear, a cholesteatoma, or excessive straining leads to symptoms of vertigo, tinnitus and hearing loss. Symptoms include intermittent vertigo, dysequilibrium and a fluctuating sensorineural hearing loss (Fetter, 2007). Fistulas may heal spontaneously over time. Historically, these have been treated with surgery, however of late, surgical treatment has become more controversial and has come under greater scrutiny due to questions about actual diagnosis and efficacy of intervention.

2.5.2 Central Vestibular Disorders

Cerebrovascular Accidents (CVAs) and Transient Ischemic Attacks (TIAs)

The vestibular regions of the central nervous system include the vestibular nuclei, vestibulocerebellum, brainstem, spinal cord, and cerebral cortex. The inner ear, brainstem and cerebellum receive their vascular supply from the vertebrobasilar artery system and disruption of the circulation can lead to ischemia and subsequent dizziness. If the infarction occurs distal to the posterior or anterior cerebellar arteries, the brainstem or the inner ear will most likely be involved. Loss of circulation to the ear results in a peripheral manifestation of vertigo and peripheral symptoms whereas infarction of the brainstem or central structures will result in central signs and symptoms. The cerebellum will often be spared if the infarction is in this location (Hain & Helminski, 2007).

Transient ischemic attacks (TIAs) and cerebrovascular accidents (CVA) occurring in the brainstem will result in vertigo, diplopia and dysequilibrium. A TIA typically lasts from 1 to 15 minutes. Hemorrhages into the cerebellum may result in ataxia, dysequilibrium, in-coordination and dizziness. The cerebellum plays an important role in coordination of gait, VOR and eye-head coordination, posture, and balance control. Damage to the cerebellum can result in ongoing and persistent difficulties with the execution of accurate, smooth and coordinated movements that are required for gaze control and balance. Gait is often ataxic. The vestibulocerebellum takes part in adaptation of the VOR and recovery of function after vestibular loss. Injury to this structure inhibits the ability of the system to recover. The cerebellum plays a big role in the maintenance of vestibular function and injury to this structure can result in significant and permanent vestibular dysfunction (Hain & Helminski, 2007).

Posterior Inferior Cerebellar Artery (PICA) infarctions, also known as lateral medullary syndrome or Wallenberg Syndrome, leads to acute onset of vertigo, abnormal eye movements, ipsilateral Horners syndrome, limb ataxia and ipsilateral hemiaesthesia on the face and contralateral hemiaesthesia on the trunk. Ischemia or interruption of the blood supply to the vestibular system or the CNS, particularly the brainstem can cause dizziness, vertigo, dysarthria, ataxia and diplopia. Normal brain cell function depends on efficient circulation. The SCCs have no collateral circulation and are therefore vulnerable to ischemia.

Dizziness resulting from decreased blood flow to the brain can also result from dehydration, orthostatic hypotension or arteriosclerosis. Presyncope or vasovagal symptoms may happen with a sudden drop in blood pressure during position changes. Orthostatic tachycardia syndrome can also occur from orthostatic hypotension. This is often preceded by symptoms of generalized weakness, headaches, blurry vision, diaphoresis, nausea and vomiting. Stress, anxiety, hypovolemia, or impaired peripheral vasoconstriction may also lead to presyncope or tachycardia. A thorough examination of the patient at the time of presentation is indicated and metabolic and cardiovascular causes need to be assessed.

Migraine Associated Vertigo:

Vertigo is seen in up to 26.5% of people with migraines (Kayan & Hood, 1984). The two often happen simultaneously. The clinical features of migraine are often hard to distinguish from those of Meniere's disease. These include motion sensitivity, phonophobia, photophobia, aural fullness, tinnitus, headaches, visual auras and vertigo. Migraine associated vertigo is intermittent, can last from seconds to days, and may be triggered by food, stress or sensory stimulation. Physiotherapy treatment involves education re: recognition and management of triggers and participation in an exercise program that encourages activity and stress reduction. Once appropriate medical management has been implemented, the symptoms typically subside and normal activities can be resumed.

Multiple Sclerosis (MS):

The initial presenting symptom in MS is vertigo in 5% of people. Eventually, up to 50% of people with MS will present with vertigo at some point in the disease (Karatas, 2008). Imbalance is seen in a large number of people with this disease. The severity of the symptoms depends on the location of the demyelinating plaques. As the name suggests, multiple areas affecting vestibular function can be involved, including cranial nerve VIII, the vestibular nuclei, the oculolomotor tracts and cerebellum. Intense vertigo may occur if the lesion is at the root entry zone of the vestibular nerve similar to an acute peripheral vestibular lesion. The duration of the vertigo is variable, lasting from hour to days. Other symptoms might include nausea and vomiting, nystagmus that beats away from the affected side and positive ENG findings. If the lesions involve the central vestibular structures, including the cerebellum, the nystagmus will be downbeating. Cerebellar signs include ataxia. As well, the patient may experience oscillopsia, dizziness, and problems with visual acuity and diplopia.

2.5.3. Peripheral plus Central Vestibular system Pathology:

Tumours:

Vestibular schwannomas, sometimes called acoustic neuromas, represent approximately 8% of intracranial tumours with incidence peaking in the 5th and 6th decades of life. A schwannoma is a benign slow growing intracranial tumour arising from the myelin forming cells, called Schwann cells, of the 8th cranial nerve. On Magnetic Resonance Imaging (MRI), it can be seen as an enhancing mass in the cerebellopontine angle that extends into the internal auditory canal. This condition presents with progressive unilateral sensorineural hearing loss. Vestibular symptoms include dizziness and imbalance. Management of small tumours involves a “wait and see” approach. Regular MRIs monitor any progression. Treatment of larger tumours is with surgery or gammaknife radiation surgery. Physiotherapy intervention post surgery typically emphasizes balance retraining and habituation exercises to decrease the symptoms of dizziness and dysequilibrium (Enticott, O’leary, & Briggs, 2005; Vereeck, Wuyts, Truijen, De Valck, & Van de Heyning, 2008).

There are a variety of other tumours that can occur at the cerebellopontine angle, and the cerebellum. These can cause symptoms of imbalance and ataxia, dizziness, pressure, hearing loss, facial pain, weakness, headaches, nausea, vomiting and nystagmus.

Aging:

Research has shown that as a person ages, degenerative changes occur within the structure and nerve cells of the vestibular system. As a person's age increases, so is the likelihood of increased dizziness and imbalance. Presbycusis or aging of the vestibular system is the most common inner ear disorder. Pothula, Chew, Lesser, & Sharma (2004) found that of the 428 patients who fell for unexplained reasons and presented to Emergency rooms in the United Kingdom, 80% had vestibular symptoms and 49% reported vertigo. In the Taiwanese national survey of vertigo (Ying-Ta Lai, Ting-Chuan Wang, Li-Ju Chuang, 2011), both the prevalence and recurrence of vertigo increased significantly with age ($P <.001$). Those 70 years or older had a prevalence of 9.2% vertigo with a recurrence rate of 32%. Women were twice as likely to develop vertigo as men. Tinetti, Williams, & Gill (2000) reported 29% of a large population of 1087 seniors aged 72 or older had been dizzy within the last 2 months. Loss of balance, dysequilibrium and unsteadiness were the most frequently described symptoms. The problem of dizziness and imbalance in the older population is considerable.

With aging, inputs from the SCCs that produce the VOR decrease as the hair cell receptors and vestibular neurons die off. After the age of 60, there is a decrease in the hair cells and vestibular neurons within Scarpa's ganglion of the vestibular apparatus. Rosenhall (1973) reported a 40% decrease in hair cells in the saccule, 24%

in the crista ampularis, and 21% in the utricles in those over 70 years old compared to those people 40 years or less. As VOR gain decreases, the ability to compensate for head movements at higher speeds is reduced, leading to retinal slip (Baloh, 1998). Combined with this, there is a decreased ability to adapt to the decreased gain making it more difficult to compensate for functional changes. Vascular changes to the microcirculation of the inner ear contribute to neurodegeneration of the hair cells and cell death (Ishiyama, 2009). Furthermore, previous vestibular disorders that may have been present at a subclinical level may now become apparent as activity levels decrease and levels of decompensation increase. Peripheral neuropathy, along with a decline in visual acuity that accompanies aging, makes it harder to use these systems to substitute for the deficiencies. These problems, along with changes to the musculoskeletal system, cerebellar atrophy, and fear of falling, changes in cognition, depression and other co-morbidities contribute to greater coping difficulties in the elderly population who have vestibular deficits.

Head Trauma:

Concussion and trauma to the head account for a large number of referrals for treatment with people who report symptoms of dizziness and vertigo (Maskell, Chiarelli, & Isles 2006). Centers for Disease Control and prevention (CDC) refers to concussion as a mild brain injury(Centers for Disease Control and Prevention, 2011). Even though the concussion may be considered mild with no loss of consciousness or evidence of injury on imaging, the symptoms experienced may be extensive and disabling ranging from headaches or migraines and poor sleep to dizziness, imbalance and decreased cognitive abilities. The forces generated to cause a concussion, either from a direct blow to the head or indirect such as a whiplash injury, can interfere with normal brain processing and disrupt the integrity of the vestibular system. The prevalence of dizziness at initial evaluation ranges from 23% to 81 % along with other accompanying symptoms. Symptoms may not always present immediately but may show up days later. While the definition of dizziness and the inclusion and exclusion criteria differs between studies, the problem is a very real one, and symptoms of dizziness can persist for years (Maskell et al., 2006).

Problems associated with disruption of the functioning of the vestibular system secondary to trauma include BPPV, a condition where calcium carbonate crystals or otoconia that sit on the otoliths become dislodged and enter the SCCs resulting in position mediated vertigo. Other possibilities include injury to the vestibular nerve, fracture of the temporal bone resulting in a dehiscence, disruption of the VIIIth cranial nerve, endolymphatic hemorrhage, post traumatic perilymph fistula due to rupture of the round or oval window and post traumatic Meniere’s disease (Alsalaheen et al., 2010). The persistence and extent of symptoms depends on the location and severity of the injury. Trauma may also result in injury to the central vestibular structures, including the cerebellum, brainstem or vestibular nuclei from sheering, micro trauma or bleeding.

2.5.4 Other:

Dizziness and imbalance can occur from other causes. Motion sickness can occur if there is conflicting sensory information from the visual system, the vestibular system and the somatosensory system. An example of this might occur while reading in a moving car. The vestibular system and the proprioceptive systems send inputs to the brainstem and cerebral cortex about motion while the visual system is sensing comparatively very little motion. When the person's consciousness becomes aware of the conflict, motion sickness develops. By focusing on a distant point such as the horizon, which provides an accurate reference as to the earth's vertical, conflicting visual disturbances can be reduced. Medication is often helpful in controlling motion sensitivity.

Peripheral neuropathy may interfere with normal balance. Difficulty sensing the ground due to decreased sensation and tactile information in the legs and feet may cause imbalance and falls. This loss of sensation also makes it harder to use peripheral somatosensory information to substitute for weaknesses within the visual and vestibular systems.

Musculoskeletal disorders of the neck, particularly osteoarthritis or spinal stenosis of the neck can impede circulation to the brain. Restricted blood flow can result in dizziness. Vertebrobasilar insufficiency (VBI) from ischemia at the vertebral artery may result in vertigo. Accompanying symptoms often include facial numbness, difficulty with swallowing or speaking, drop attacks, visual field deficits or double vision. This can be screened by the therapist with a simple VBI screening test done in sitting or in supine. Cervical spondylosis can also trigger vertigo.

Hyperventilation can cause dizziness due to changes in the levels of oxygen and carbon dioxide (CO_2) circulating in the blood. Lower levels of CO_2 from rapid breathing can respiratory alkalosis producing symptoms of dizziness. This is not uncommon in patients who present with a high level of anxiety. Up to 60% of chronically dizzy patients have an associated anxiety disorder. These types of patients feel symptomatic when out in open spaces such as large department stores or shopping centres (Staab & Ruckenstein, 2005). Many of these patients describe symptoms of lightheadedness, subjective imbalance, and motion sensitivity but display no clinical signs of vestibular dysfunction. This type of non-specific dizziness may present with vague, subjective feelings of dizziness. Psychogenic dizziness which is non-specific in nature includes depression, generalized anxiety disorder and panic attacks. Light-headedness from hyperventilation is not uncommon in these types of clinical presentations. These types of symptoms may be reproduced with voluntary hyperventilation.

2.6 Vestibular Testing and Diagnostics:

2.6.1 Nystagmus:

The VOR and optokinetic systems are used to stabilize gaze. Nystagmus is a reflex that is generated when there is no foveation. Under normal conditions, when there is no fixation or in the dark, the angular VOR (aVOR) relies on signals generated by the SCCs during head rotation to keep gaze stable through compensatory eye movements. During head rotation, vestibular nystagmus moves the eyes horizontally in a compensatory manner in the direction of the head movement towards the end of their range within the orbit. This is known as the slow phase of nystagmus and is driven by the vestibular system. The eyes then quickly return to the centre of their gaze during what is called a fast phase. The direction of the nystagmus is defined by the direction in which the fast phase is moving. Nystagmus can also be generated using large-field optokinetic stimulation. This is referred to as optokinetic nystagmus (OKN) and is identical in appearance to vestibular nystagmus in that there are slow phase and fast phase components. The slow phase of OKS is visually driven, whereas the fast phase is not (Goldberg et al.1991, Land 2006).

Nystagmus can be used in the diagnosis of peripheral vestibular and central conditions. Spontaneous nystagmus that is seen after acute peripheral vestibular lesions is caused by an imbalance in the tonic neural firing rate between the vestibular nuclei on lesioned side and the unopposed neural impulses from the intact side. It can be seen in acute conditions even when the head is not moving and can be suppressed by fixation. Spontaneous nystagmus that is not suppressed by fixation typically represents a brainstem or cerebellar abnormality. In peripheral disorders, the fast phase of the nystagmus beats away from the lesioned side and the slow phase towards the lesioned side. It is strongest immediately after the lesion occurs and gradually diminishes over time and often disappears over the next few weeks. In central lesions, the most commonly seen nystagmus is a pure downbeating direction with no torsional component.

Testing for vestibular disorders is limited. There are, however, a few useful diagnostic tests that can help in the diagnosis of peripheral vestibular disorders

2.6.2 Electronystagmography (ENG):

This is perhaps the most widely used diagnostic tool for determining a peripheral vestibular dysfunction. “Calorics” as it is sometimes called, measures the function of the horizontal SCCs along with a portion of the superior vestibular nerve. It is useful in determining whether the lesion is peripheral and in isolating the side of the lesion. The canals are stimulated by thermal irrigation of water at 30°C and 44°C. When a temperature gradient is detected by the horizontal canal, the vestibular nerve is either excited or inhibited and nystagmus is created. Warm water causes an excitatory response resulting in nystagmus where the fast phase beats towards the ear being irrigated whereas cold water does the opposite. The velocity of the slow phases of nystagmus is calculated and quantified using Jongkees formula allowing the two sides to be compared to each other and a diagnosis to be made (Barin, 2008; Tusa, 2007). The test has its limitations in that it is able to test only the horizontal SCCs. Furthermore, it tests the canals while the head is static and does not measure the head during function. It is able to test reflexes and generate a response to a mechanical stimulation of the hair cells but does not measure vestibular function during actual head movement or during natural vestibular stimulation. This test is important in determining pathology and possible causes of the dysfunction but provides no information about functional or behavioral consequences that are caused by the deficit.

2.6.3 Vestibular Evoked Myogenic Potential Test (VEMP):

This is the only test that can assess the function of the saccule and the inferior vestibular nerve. It is produced via a three neuron arc involving the saccule, the vestibular nuclei via the inferior vestibular nerve and the ipsilateral motoneurons of the sternocleidomastoid (SCM) muscle via the descending medial vestibular tract. The person is tested in supine while the neck is actively flexed. The saccule, which is sensitive to sound, is stimulated in the ear by a series of clicks or tones at a rate of five clicks per second. Electrodes over the SCM record the response of the muscle to the tone via electromyography (EMG). The stimulus will inhibit the SCM response resulting in an on/off response during the clicking. If the saccule has been damaged, there will be an absence of responses on the side of the damaged ear. It's sensitivity is 31% to 90% and it's specificity is 86% depending on the vestibular diagnosis (Aiken & Murnane, 2007; Halmagyi & Curthoys, 2007; Tusa, 2007).

Again, as with the ENG test, this test measures a response to a stimulus that occurs during a static head position. It records static vestibular function and therefore is valuable for diagnostic purposes but does not assess function during normal head movement.

2.6.4 Rotary Chair Testing:

This test assesses the horizontal canals and the superior vestibular nerve. Eye movements are recorded using electrooculography. Horizontal eye displacement is measured during sinusoidal rotations of the chair during velocity step testing or during constant velocity optokinetic stimulation. The gain and slow phase of the eye movements are plotted allowing for measurement of VOR gain, phase and time constant. (Arriaga, Chen, & Cenci, 2005; Brey, McPherson, & Lynch, 2007; Tusa, 2007)

This test, unfortunately, is not readily available for use in many centres. The equipment is expensive and bulky. It is, however, more sensitive to bilateral vestibular dysfunction and can measure loss of VOR gain even with central disorders. Sensitivity of this test has been found to be 66% to 71% and specificity 54% (Tusa, 2007).

2.7 Clinical and functional tests:

Clinical and computer-based evaluations will be carried out in the present study and the results compared and evaluated. The following sections describe the Dizziness Handicap Inventory (DHI) which is a questionnaire used to assess perception of dizziness, the Visual Analogue Scale which is a self rating scale for symptoms, the Dynamic Visual Acuity Test (DVA) which is a clinical test of gaze stability, the Dynamic Gait Index (DGI) which is a clinical test of balance and other tests which are often part of the evaluation process.

2.7.1 Dizziness Handicap Inventory (DHI):

The Dizziness Handicap Inventory (DHI) is a self-rating questionnaire based on 25 questions used to quantify a patient’s own perception of his or her dizziness and its impact on their life. It was developed by Jacobson and Newman (1990). The questionnaire is divided into 3 domains: 7 questions relating to ones perception of physical function, 9 questions relating to emotional function and 9 questions pertaining to functional ability. The test is graded out of 100 (where 100 is extreme dizziness and 0 is no dizziness) and questions are answered with a simple yes, no or sometimes. Each “yes” answer is given a rating of 4 points, a “sometimes” gets 2 points and a “no" gets 0 points for a total DHI (tDHI) score of 100. Jacobson et al. (1990) found high internal consistency for the total score $(\alpha = .89)$ and test retest reliability was excellent (ICC=.97, P<.0001). The test is also sensitive to changes on re-testing (Enloe & Shields, 1997). It is valuable when assessing the effectiveness of physiotherapy intervention. Fielder, Denholm, Lyons, & Fielder (1996) found evidence of discriminant validity between the DHI and the number of episodes of dizziness. A correlation between the tDHI score and the 8 dimensions of the Short Form 36 Health Survey Questionnaire was determined (Spearman r=.53-.72, p=.001) demonstrating convergent validity. Fielder et al. found a negative correlation between high scores on the SF36 and low scores on the DHI. A high score the SF36 and a low score on the DHI both indicate a better perception of one’s health.

Asmundson, Stein, & Ireland (1999) did a factor analysis of the 25 questions and the three subscales of the DHI as described by Jacobson. After analyzing the data from 95 patients and comparing it to five other questionnaires that assess vestibular symptoms, anxiety and mood they found that the results of the factor analysis did not support the validity of the structure of three domains used in the DHI. They cautioned against using the three subscales as they may not represent a valid assessment of the domains as described by Newman. Similar findings have subsequently been found by several other investigators (Duracinsky, Mosnier, Bouccara, Sterkers, & Chassany, 2007; Pérez-Garrigues, Kuessner, & Benecke, 2007; Tamber, Wilhelmsen, & Strand, 2009; Vereeck, Truijen, Wuyts, & Van De Heyning, 2007). A factor analysis of the three domains done in the Norwegian study (Tamber 2009) on 92 patients with vestibular dysfunction confirmed that the differences in factor structure were not fully representative of the subscales as described in the original scale and hence these subscales were not treated individually. As a result, it was recommended that only the tDHI scores be used, consistent with what the other investigators had recommended. Tamber's study demonstrated high internal consistency with Cronbach's alpha coefficients. Construct Validity showed moderate correlations between the DHI and other questionnaires (ranging from .50 to .69), discriminant ability was excellent in identifying patients with and without disability, test re-test reliability (n=27) was ICC = .90, and responsiveness to change on retesting was identified. A 20 point change in score on retesting of the tDHI was recommended as identifying those who had and hadn't changed.

See Appendix B for copy of DHI

2.7.2 Ranking Scales:

Visual Analogue Scale:

The visual analogue scale is a self-rating scale from 0-10 that measures the severity of symptoms where 0 is no symptoms and 10 is the most severe symptom imaginable. Traditionally this scale has been used to measure pain, however it can be used to rate other symptoms. It has been used to measure dizziness post acoustic neuroma resection (Herdman, Clendaniel, Mattox, Holliday, & Niparko, 1995), acute unilateral vestibular hypofunction or central dysfunction (Kammerlind, Bergquist Larsson, Ledin, & Skargren, 2005) and with patients who had migraine associated vertigo (Whitney, Wrisley, Brown, & Furman, 2000). Kammerlind et al. found the test retest reliability to be 95% and an ICC to be between .85 and .96 in patients with peripheral vestibular dysfunction. The ICC was lower in patients with central dysfunction. In an earlier study by Kammerlind, Håkansson, & Skogsberg (2001), the VAS rating was found to be significant (p=<.01) when comparing people who had treatment for non peripheral vertigo and imbalance with those who received no treatment. Whitney & Wrisley et al. (2000) found that in a retrospective study of 39 patients with migraine associated dizziness the VAS was able to demonstrate change of symptoms over time.

Therapist Ranking of performance:

Psychometric measurement of performance can be rated quantitatively using categorical numbers in order to collect information about the quality of the movement and balance. This can be done to index balance performance through observation. The rater can select a number which best represented the quality of the characteristic being assessed similar to the study by Shumway-Cook & Horak (1986) who rated the balance of people during the CTSIB on a scale of 1 to 4 based on observed performance where 1 represented minimal sway, 2 represented mild sway, 3 represented moderate sway and 4 represented a fall.

2.7.3 Dynamic Visual Acuity Test (DVA):

The DVA test is an assessment tool used to assess the visual acuity of clients with vestibular dysfunction. During activities of daily living, particularly walking, the head is constantly moving affecting visual acuity. In order to see clearly, gaze stability must be maintained to minimize retinal slip. The DVA measures the difference in visual acuity on a standardized eye chart when the head is still and gaze is stable and then compares it to when the head is moved passively at a specified amplitude and frequency. The difference between the two lines is a measure of visual acuity. A loss of 0 to 2 lines is considered normal, whereas loss of 3 or more lines represents a loss of VOR function (Tusa, 2007, Goebel, 2001).

Most studies to date that have measured gaze stability during head motion have done so with a computerized DVA test. The computerized version of this test, developed by Neurocom™, has shown to be reliable and the sensitivity and specificity have been established (Herdman, S; Tusa, R; Blatt, P; Suzuki, A; Venuto, P; Roberts, 1998). They showed an interclass correlation coefficient (ICC) of r=.87 with normals and an ICC of r=.83 in their patient population. The sensitivity of the test was found to be 94.5% and the specificity of the test was 95.2 % which was considered to be a reliable determinant of those people who had vestibular dysfunction.

The computerized version of this test has been described by several authors (Demer, Honrubia, & Baloh, 1994; Herdman, Hall, Schubert, Das, & Tusa, 2007; Herdman, Schubert, Das, & Tusa, 2003; Herdman, Tusa, Blatt, Suzuki, Venuto & Roberts, 1998; Honaker & Shepard, 2011; Mohammad, Whitney, Sparto, Jennings, &

Furman, 2010). It is not, however, available in most clinical settings. A clinical version of this test has also been described (Goebel, 2001; Tusa, 2007; Venuto et al., 1998). In the clinical method, the patient is asked to read the lowest line possible on an eye chart while the head is still. Next, the patient is asked to read the best possible line (smallest letters) on the eye chart while the examiner passively moves the head back and forth 1 to 2 inches at a rate of 2 hz. The ability to maintain fixation of the object on the fovea is dependent on the VOR which is the main reflex involved in compensatory eye movements during head movements at this speed. Decrements of visual acuity are measured by the difference between the lowest line read when the head is still and the lowest possible line read when the head is moved. A difference of 0 lines means that there is no decrement in visual acuity is whereas a loss of 3 or more lines between the static and the moving acuity indicates a deficit in vestibular and VOR function. Venuto et al. (1998) demonstrated high interrater reliability among 3 different clinicians (ICC=.84 to .98) when testing a sample of 41 patients with vestibular deficits.

A recent study (Mohammad et al., 2011) compared two different computerized methods of measuring gaze stability and VOR function during head movement. When the head is moved side to side, head velocity is detected via stimulation of the SCCs and production of the VOR. The first method, called the computerized dynamic visual acuity (cDVA) test, measured visual acuity while actively moving the head continuously back and forth in a sinusoidal fashion as the size of the optotype was gradually made smaller. The visual acuity of the smallest optotype identified measured while the head was moving was compared to the smallest optotype identified when the head was still and the difference between the two lines recorded. This is referred to as dynamic visual acuity. Both vertical and horizontal directions were tested. Right and left scores and up and down scores were compared to each other.

In the second computerized method, called the gaze stabilization test (GST), the same optotype was used as in the cDVA test. This time, however, instead of the letter changing size, the velocity of active head movement increased. The velocity of the head movement was monitored by a sensor mounted on the head. The maximum velocity of head movement achieved was recorded when the orientation of the optotype was no longer correctly identified.

28 patients with peripheral, central or mixed peripheral and central vestibular dysfunction were recruited for the study. They were tested twice in one day and again one week later. Test-retest reliability of the GST scores was poor (ICC: 0.0-0.48). For the cDVA test, absolute reliability (highest line achieved before subtracting the lowest line) was statistically significant (ICC = .64 to.83). There were no statistical differences in the cDVA individual scores between lesioned and non-lesioned sides.

There was an inverse relationship found between the GST and the cDVA. The ability to read the optotype at higher velocities on the GST reflected better cDVA scores demonstrating overall better visual acuity. Patient symptom scores, based on the VAS scores were not correlated to cDVA or GST scores. The reliability of the tests scores between the cDVA and GST test was poor demonstrating inconsistencies between two tests that measure the same reflex. Further work needs to be done to standardize visual acuity testing. One possible explanation for the lack of reliability of the scores of the two tests is the natural variation in symptoms patients with vestibular dysfunction experience from day to day.

Another important consideration in using these tests is that they only examine visual acuity while looking at a stationary target. In reality, gaze stability within the natural environment requires that visual acuity be maintained while objects are moving. The inability to track a moving object and maintain foveation will result in visual blurring and other destabilizing symptoms. There are degrees of difficulty when it comes to maintaining visual acuity on the fovea. Keeping an object fixated on the fovea is much easier to do when the object is stationary. It becomes more difficult to do this when the head movement is being actively generated in a predictable manner. This task becomes increasingly more difficult during unpredictable movements. The current study examined the ability to maintain visual acuity and foveation on a moving target while the head is stationary, while the head was moving predictably and during unpredictable movements.

Dannenbaum et al. (2005) looked at a clinical test of the DVA to determine its effectiveness in assessing people with vestibular dysfunction. 31 normals were compared to 10 patients with vestibular hypofunction. The subjects were tested at 10 feet while reading the lowest possible line on a Snellen eye chart and an E chart with the head at rest and again while the therapist passively oscillated the head through 40° of head ROM at the following frequencies: .5 hz., 1.0 hz., 1.5 hz., and at 2 hz. The best line (smallest letters) that could be correctly read was recorded. At 1.5 hz, the visual acuity of normals did not change but at 2 hz, the visual acuity began to decline in 4 out of the 31 normals. Subjects with a unilateral deficit showed normal visual acuity at .5 hz. but began to show varying degrees of loss of visual acuity as the frequency increased to 1.5 hz. and higher. There is some disagreement between authors as to what is the best frequency. Several studies have recommended using frequencies of 1 Hz (Barber, 1984; Longridge, NS; Mallinson, 1984; Mallinson, 1987) whereas others have recommended using 2 Hz head movements (Tusa, 2007; Goebel 2001). A later study by Dannenbaum et al. (2009) noted that frequencies of 1.5 and 2 hz were able to differentiate people with UVL from those who did not have a hypofunction as long as the frequency of movement was high enough. They recommended that the frequency of head oscillations be standardized.

There are 3 main types of eye charts used when testing visual acuity. They include the Snellen eye chart, the E chart and the Early Testing Diabetic Retinopathy Study (ETDRS) Chart. The most commonly used charts are the Snellen and the ETDRS charts. There are various modifications on each of these. While there is no standardized eye chart in general practice, the Food and Drug Administration is now requiring that the ETDRS charts be used for all registered clinical trials (Kaiser, 2009). The 1982 modified version of the ETDRS chart has become the “gold standard” for vision testing in clinical trials due to better precision, more accurate measurements and better test-retest variability (Kaiser, 2009). It is administered at 4 meters (13 feet). The modification most commonly used with this chart has 5 letters per line with a step variation of 0.1 logMAR between lines for a total of 14 lines or 70 letters in total. Sloan letters are used. These are 10 specific standardized non serifed letters of a standard size made within the space of a square and having a specific stroke width equaling one fifth of the letter size. The spacing between letters is one letter width and between lines is one letter height of the smaller letter.

Problems associated with the clinical DVA include the possibility of memorizing the letters on repeated testing, difficulty with controlling velocity and frequency, and the problem of being able to read the letters at turns when the head comes to a temporary stop. As well, there is no standardized chart that has been adopted by all clinicians so results among clinicians using different charts may be different. The test however is one of several clinical tests that is helpful in assessing people who have vestibular deficits provided that the head is moved fast enough. It has been shown to an effective way of measuring improvement over time.

2.7.4 Dynamic Gait Index (DGI):

The Dynamic Gait Index (DGI) is a clinical test used to evaluate disturbances or difficulties with ambulation and is used to assess fall risk. It consists of 8 different tasks performed in walking consisting of walking on a flat surface, walking with vertical and horizontal head movements, changing gait speeds while walking, walking around and over obstacles, turning around and stopping and also climbing stairs. It is a performance-based measure of balance that has been validated for use with vestibular patients (Whitney, Hudak, & Marchetti, 2000; Whitney, Wrisley, & Furman, 2003) and shows excellent test-retest reliability (Hall & Herdman, 2006; Hall, Schubert, & Herdman, 2004; Marchetti, Whitney, Blatt, Morris, & Vance, 2008; Shumway-Cook, Gruber, Baldwin, & Liao, 1997; Wrisley, Marchetti, Kuharsky, &

Whitney, 2004). The test is graded out of a total of 24 and each of the 8 separate tasks is graded on a scale of 0 to 3 where 0 represents inability to perform the test and 3 represents a normal score. A score of 19 or less out of 24 has been associated with an increased risk for falling. Shumway-Cook et al. (1997) found that the inter-rater reliability of the DGI was ICC = .96 when correlating subject variability to total variability at initial assessment. One week later, on retesting, the test-retest reliability was ICC=.98. This test has been found to be a sensitive tool in identifying older adults at risk for falling and those with balance and vestibular disorders regardless of age (Marchetti et al., 2008; Whitney, Hudak, et al., 2000). One criticism of this test is that it has a low ceiling effect and does not capture the deficits in those people with higher balance function and less impairment (Pardasaney et al., 2011).

See Appendix A for DGI

2.7.5 Halmagyi Head Thrust Test:

The Halmagyi head impulse test was first described by Halmagyi in 1998 (Cremer et al., 1998). It is a simple bedside test to check the integrity of the horizontal semi-circular canals and the gain of the VOR. It is performed with a passive, unpredictable, high velocity and small (20° to 30 °) head thrust (up to 4000°) while the head is pitched down at 30° corresponding to the angle of the plane of the horizontal semi-circular canals. A healthy SCC can compensate for the movement of the head in one direction by moving the eye in an equal and opposite direction. The ability of the patient to maintain focus on a central target, such as the examiners nose, demonstrates a VOR with a gain of 1 or nearly 1. A lesioned canal will have a low VOR gain and demonstrate a corrective saccade back towards the target due to a reduced gain and an inability to maintain fixation on the target. This corrective saccade can often be observed by the examiner with a simple bedside test and is a helpful screening tool for VOR loss. A negative test is not always representative of a normal VOR. In the acute stages of the disorder, however, a positive test is indicative of a peripheral vestibular lesion.

Schubert, Tusa, Grine, & Herdman (2004) determined the sensitivity and specificity of the head thrust test in 176 patients with UVL and BVL in a retrospective study over 6 years. The overall sensitivity of this test was found to be 71% for UVL and 84% for BVL. The sensitivity was higher for complete UVL'S at 88% and for complete BVL's at 100%. The overall specificity of the test was 82%. The sensitivity of the test was improved by ensuring the head was pitched down 30° in line with the horizontal semi-circular canals and by performing the head thrusts in an unpredictable manner. This test is sensitive to the detection of severe impairment of the canals. It is a helpful test in a battery of clinical tests of vestibular dysfunction.

2.7.6 Other:

Another useful test in the diagnosis of peripheral vestibular disorders includes an audiogram, particularly in the diagnosis of Meniere's disease. Less available tests also include computerized dynamic posturography and the SOT, cDVA test, and the subjective visual vertical test for testing utricle and superior vestibular nerve function. Clinical testing includes observing eye movements, tests of gaze stability, and the use of validated questionnaires which provide information on the impact of vestibular symptoms on quality of life and perception of dizziness.

2.8 Summary:

The visual system contributes significantly to the maintenance of balance and to an increase in head stability in space in people with decreased somatosensory inputs in both standing and while walking on a treadmill (Cinelli, Patla, & Stuart, 2008). It works together effectively with the vestibular system when there are decreased somatosensory system inputs. Visual, vestibular and somatosensory inputs interact with each other to maintain orientation in space and to navigate safely within ones environment. The CNS uses this information to assist with perception of body orientation in space and motion, to help with the maintenance and recovery of balance and for eye-head coordination.

Maintaining balance during daily activities of living requires the ability to perform large head and trunk movements with accuracy and precision. Feed forward mechanisms are required during preplanned and anticipated movements. Balancing tasks involving large movements become more difficult on compliant surfaces resulting in movement errors and potential loss of balance. In these situations, feedback mechanisms are needed to quickly restore balance because the ground reaction forces are unpredictable and stability requirements cannot be anticipated (Betker, Szturm, et al., 2005; Desai et al., 2010). A multidimensional approach is required in the assessment of standing and walking in people with vestibular loss because different functional tasks place unique biomechanical and physiological demands on the balance system depending on the characteristics of the support surface and the visual environment (Duysens et al., 2008). The Dynamic Balance

Assessment (DBA) considers both feed forward and feedback methods while performing balance tasks and uses both predictable and unpredictable balance control mechanisms.

Test protocols and data analysis methods have been developed to electronically quantify balance and gaze stability under different sensory conditions and levels of difficulty while the head is moving. In the present study, balance during standing and walking will be recorded under various conditions including varied support surfaces while performing different visual tasks. Gaze stability will be measured during smooth pursuit and gaze shifts as the head is moving. These measures, along with the DHI, DVA and the DGI will provide evidence of a physical construct of balance impairment, gaze instability and dizziness. This will offer a better understanding of the mechanisms that contribute to decreased mobility, eye-head coordination, falls and activities of daily living. It will also provide a rationale for targeted interventions designed to improve balance, mobility and gaze functions in the clinical setting and for telerehabilitation applications.

Studies to date have not demonstrated how foveating on a moving target impacts gaze and balance while actively tracking a moving target during head motion under varied balance conditions. Our goal is to study gaze control and balance during high and low levels of foveation on a moving target during head movement under different balance conditions and to examine this within the context of pathology and disease. It will bring together readily available, cost effective and performance-based technologies into a database that objectively measures function and changes in performance. This has the potential to be incorporated into a treatment program which can be delivered and monitored from home and has positive implications for distance and remote programming and monitoring including telerehabilitation.

Chapter 3: Study Objectives

The purpose of this study was to examine the psychometric properties of electronic measures of dynamic balance and gaze control in a sample of people with unilateral and bilateral peripheral vestibular hypofunction. We designed a new assessment tool that was able to incorporate various balance tasks including the mCTSIB and walking while simultaneously performing specific visual tasks. These various balance and visual tasks were chosen so as to emulate a broad range of different conditions that a person might encounter during the course of a normal day and to study how these tasks affected each other. We expected that as the balance demands increased, there would be a decrease in the ability to accurately track a moving target. We also expected that as visual demands increased, there would be an increase in body sway and a decrease in visual tracking performance.

Research has shown that balance can be measured under different surface and visual conditions as shown with the Sensory Organization Test (SOT) and mCTSIB and as is described in National Institutes of Health (NIH) Toolkit for vestibular function (Rine et al., 2013). In these examples, the balance testing was limited to standing quietly and holding the head stationary under varied surface conditions. No walking or visual tracking was required.

It has also been shown that visual acuity can be measured in sitting using the cDVA test (Rosemarie Rine et al., 2012) and the GST (Mohammad et al., 2011). The

NIH toolkit uses the cDVA test to screen vestibular and visual function and to quantify visual acuity during head movement in sitting. These visual tests are done in sitting with no consideration of the additional balance costs required in standing or walking.

There have been numerous studies to date showing that as physical load is increased from a fixed surface to a sponge surface, there is a decrease in postural stability (Allum et al., 2002; Betker et al., 2005; Creath et al., 2005; Desai et al., 2010; Shumway-Cook & Horak, 1986; Strang, Haworth, Hieronymus, Walsh, & Smart, 2011). Little is known, however, about how increases to physical loads affect visual performance during head rotation. As well, little is known how increases to visual loads affect balance and visual performance while actively rotating the head while tracking a moving target or during unpredictable movements of the head that happen while standing on sponge surface or while walking. The new assessment tool is able to measure balance under varying surface conditions and balance requirements while simultaneously performing different visual tasks under different levels of foveation.

Objective 1:

For an assessment tool to be reliable it must be reproducible and consistent under the different conditions during which it will be applied. Relative reliability describes the extent to which the measure is able to maintain consistency among individuals and is measured with the intraclass correlation coefficient (ICC). Absolute reliability is the degree to which measurements will be maintained between tests. This is reported using the standard error of measurement (SEM) which is defined as the square root of the error or within-client variance (Stratford & Spadoni, 2003; Streiner & Norman, 2008).

The first objective of this study was to determine the test- retest reliability of our new assessment tool to determine how consistent and stable it was over time. The assessment was done twice over 5 to 7 days where we believed that there had been no change with the client. The student “t” test was used to determine any systemic differences and potential bias between the means of the two tests(Atkinson & Nevill, 1998; Wier, 2005) and ICC were used to determine relative reliability of the test and consistency between tests. Group means and standard deviations were used to calculate the ICC to determine the with-in client variance. The ICC is used to determine how consistent and stable the test is over different days (Hassard, 1991; Streiner & Norman, 2008). Absolute reliability was used to determine measurement error among clients between tests and was calculated using the SEM. SEM is used to determine the range or confidence interval within which the estimated measure of a person’s true score will fall. When a clinical measure is obtained, the measure is only true insofar as it will fall within a certain range or confidence interval called the SEM. To obtain a score that falls within a 95% confidence interval, take the score obtained which is an estimate of the true value of the score ± SEM x 1.96 (which represents the z-value for 95%). A larger SEM represents a lower reliability and less precision. Most measurements have some error, therefore the possibility of obtaining the identical scores on retest will be unlikely (Riddle & Stratford, 2013; Streiner & Norman, 2008; Wier, 2005).

Our sample size of 30 was derived from the calculations for ICC based on a lower 1-sided 97.5% confidence interval according to Stratford and Spadoni and Wilhelmson (Stratford & Spadoni, 2003; Wilhelmsen, Strand, Nordahl, Eide, & Ljunggren, 2008). Whitney et al. (2012) categorized ICC for test–retest reliability comparing the SOT with accelerometry with the following four groups: poor (0–0.4), fair (0.4–0.59), good (0.6–0.74), and excellent (0.75–1).

Hypothesis 1: The scores of the computerized measures of dynamic balance and gaze control will demonstrate test-retest reliability in people with peripheral vestibular hypofunction.

Objective 2:

Convergent validity is used to measure how well two different measures are related to each other where they are believed to be assessing the same attribute. The second objective of this study was to measure how well the scores on the computerized balance, gait and gaze control tests correlated with the results from the clinical outcome measures of the DVA and the DGI which are assumed to measure the same construct, as well as the DHI questionnaire which measures perception of dizziness.

Hypothesis 2: Scores of the computerized measures of dynamic balance and gaze control will demonstrate convergent validity between the new assessment tool and the DVA, DGI and the DHI in people with peripheral vestibular hypofunction.

Objective 3:

Construct validity is used when testing the theoretical concept that a new tool or method of evaluation being developed will be better able to objectively measure and improve upon current methods that are already in use (Finch, Brooks, Stratford, & Mayo, 2002; Streiner & Norman, 2008). The current study tested whether the new tool being developed, called the Dynamic Balance Assessment, could objectively measure balance and gaze control in people with vestibular hypofunction and extend the scope and breadth of the evaluation methods that are presently being used. The theoretical construct examined was that as balance demands increased from standing on a fixed surface to a sponge surface that there would be a decrease in visual tracking performance which is measured by the coefficient of determination (COD). Also, as visual tracking demands increased that there would be an increase in body sway and a resulting decrease in stability as measured by increases in COP and a decrease in visual tracking performance as measured by COD. A one way repeated measures ANOVA was performed to examine the effects of increasing physical demands and visual tracking demands on balance, gait and gaze performance measures.

Hypothesis 3: The scores of the computerized measures of dynamic balance and gaze control will demonstrate construct validity in people with peripheral vestibular hypofunction in situations where: 1. increases to physical load will cause a decrease in visual tracking performance and 2. increases in visual load will cause a decrease in visual tracking performance and a decrease in postural stability.

Chapter 4: Methodology:

4.1 Participants and recruitment:

We studied thirty people with unilateral (n=20) and bilateral (n=10) peripheral vestibular hypofunction. These people were recruited from patients seen in the vestibular physiotherapy clinic at Health Sciences Centre, Winnipeg, Manitoba. They were selected based on a complete clinical neurotological assessment and screening involving assessment of nystagmus with and without fixation using video infra red camera, Halmagyi head impulse test, Dynamic visual acuity test, Head shaking test, assessment for BPPV, and a complete oculomotor and balance assessment. All patients were assessed by the principle investigator who is an experienced physiotherapist skilled in the evaluation and treatment of vestibular patients.

4.1.1 Inclusion and exclusion criterion:

1. A confirmed diagnosis of vestibular hypofunction based on at least one or more of the following:
    - i. Positive ENG with a peripheral loss of function 23% or greater or combined total loss of less than 50
    - ii. A clear positive Halmagyi head thrust test
    - iii. Positive result on the dynamic visual acuity test.
    - iv. Stable symptoms
    - v. Good understanding for the reason for the study and those able to provide informed consent

Exclusion criterion:

2. i. People who could not understand English
    - ii People with balance problems for reasons other than vestibular disorders such as arthritis or other musculoskeletal disorders, or people with residual neurological weakness
    - iii. People requiring a walking assist such as a cane or walker.
    - iv. Active BPPV
    - v. Any acute or unstable medical conditions

Study participants were seen twice within 7 days. Each session took between 45 to 60 minutes. This included the time required to fill out the consent form and complete the assessment. The sessions took place at Health Sciences Centre, on the third floor of the Rehab Hospital room 345, 800 Sherbrook St. Winnipeg, MB, which is part of the clinical research laboratory of Dr. Tony Szturm.

Not all of the patients seen in the physiotherapy clinic were referred from ENT specialists who order the ENG testing in our region therefore the added inclusions criteria listed above, specifically the Halmagyi Head Thrust Test and the Dynamic Visual Acuity Test were also used. When seen in combination, these tests have been shown to provide a strong basis for a diagnosis of vestibular hypofunction. (Cremer et al., 1998; Dannenbaum et al., 2009; Longridge, NS; Mallinson, 1987; M. Schubert, Tusa, Grine, & Herdman, 2004). Of the thirty subjects, twenty-five patients had positive ENG’s. Of the remaining five without ENG testing, three had both positive Halmagyi Head Thrust Test plus a positive DVA score (one of whom had perforated tympanic membranes and could not be tested with ENG), and two of those had vestibular nerve ablations with no ENG testing done post ablation. Vestibular loss ranged from 23% unilateral loss to 100% complete bilateral loss.

4.2 Data Recording and Instrumentation:

4.2.1 Clinical Assessment Tools:

The Dynamic Visual Acuity Test (DVA), the Dynamic Gait Index (DGI), and the Dizziness Handicap Inventory questionnaire (DHI) were all recorded prior to testing. The modified Clinical Test of Sensory Interaction on Balance (mCTSIB) was recorded simultaneously as the same tasks were being performed during the experimental conditions.

1. The DGI evaluates disturbances or difficulties with ambulation and is used to assess fall risk. It consists of 8 different tasks performed in walking and is graded out of a total of 24. Each of the 8 separate tasks is graded on a scale of 0 to 3 where 0 represents inability to perform the test and 3 represents a normal score. See Appendix A for DGI

2. The DHI is a self-rating questionnaire based on 25 questions used to quantify a patient's own perception of his or her dizziness and its impact on their life (Jacobson and Newman, 1990). The test is graded out of 100 and the questions are answered with a simple yes, no or sometimes. Appendix B for DHI

3. The visual analogue scale is used to rate one's severity of symptoms on a scale of 0 to 10 where 0 is no pain and 10 is extreme pain. In our study, the subjects ranked their own perception of dizziness after each task was performed. This was then correlated to their perception of dizziness based on the DHI.

4. Therapists ranked the balance performance of each subject after each task to index balance performance through observation. The rater selected a number which best represented the quality of the characteristic being assessed with a rating between 1 and 4 where 1 represented good balance, 2 represented fair balance, 3 represented poor balance and 4 represented a loss of balance or fall. These numbers were then correlated to the objective computer-generated measurement of balance.

5. The clinical DVA test is an assessment tool was used in assessing the visual acuity of clients with vestibular dysfunction using a standardized ETDRS eye chart. The score was calculated based on the difference between two lines when the head is still and gaze is

stable and compared it to when the head was moved passively at a speed of 2 Hz. A difference of 0 lines to 2 represented little to no decrement in visual acuity whereas a loss of 3 or more lines between static and moving acuity represented a deficit in vestibular and VOR function. See Figure 1 for ETDRS eye chart

4.2.2 Electronic Data Recording and Instrumentation:

A 50.8 cm x 50.8 cm x 10.16 cm sponge pad (compliant surface) was used to stand on as described in Desai et al (2010). A 25.4 cm x 40.64 cm x 1.91 cm wooden board was placed on top of the sponge to distribute the forces equally with the medial borders of the feet 10 cm apart. A medium density sponge, with a density of 22.66 kg/m^3 and a 25% indentation force deflection of 13.64 kg was used for people who weighed 55 kg or more. A force sensor array (FSA) pressure sensing mat (Verg Inc., Manitoba, Canada) was used to compute vertical COP position for all standing tasks. The FSA pressure mats are constructed of thin, flexible piezo-resistive material and can be placed on top of different types of support surfaces, including the sponge pad surfaces. The FSA mat consists of an array of 256 piezo-resistive sensors (16 by 16) and each sensor covers a surface area of 2.8 cm^2. Each sensor was sampled at 30 Hz, from which the vertical COP in the anterior-posterior (AP) and medial-lateral (ML) was computed. See Figure 2 for sample of FSA recording of COP and an XY plot of COP in AP and ML directions. See Figure 3 for set-up of FSA on sponge. COP for walking could not be determined using the FSA pressure mat.

A DC magnetic motion tracking system Motion Star (Ascention Tech., USA) with a 10 mm sensor was used to record 3D linear position of the head. The miniature sensor was attached to a light weight head band which also supported the motion mouse described below. See Figure 4.

A Gyration motion air mouse was secured to a head band and used as the computer input device to control on-screen cursor motion with head rotation for left to right. This Air Mouse has inertial sensors used to derive angular position signals. With this simple method, seamless and responsive hands-free interaction with the computer application was made possible. This devise is commercially available for less than $100.00. See Figure 5.

A custom computer application was developed consisting of a visual tracking module with a bright visual target that moved horizontally across a computer monitor at a fixed amplitude (80% of the monitor width) and a frequency of 0.5 Hz. A 76 cm monitor was positioned at eye-level and 75 cm away from the study subject. This positioning resulted in horizontal head rotations of between 35 to 40 degrees to the left and to the right of centre. Two tracking tasks were performed.

a) Closed loop tracking (Closed loop tracking with respect to head hereafter referred to as CL): In this task, two separate cursors appeared on the screen simultaneously. The target cursor, displayed as a colored circle was controlled by the computer and moved across the screen in a predictable, sinusoidal pattern as described above. The second cursor, a brightly colored paddle, was controlled by the subject with the head tracking air mouse mounted to the head and slaved to head rotation (See Figure 6). The required task was to overlap the two cursors during motion from the right to left edges of the monitor. This requires continuous foveation to determine the amount of overlap (error) between cursor and target. Participants were required to sit, stand or walk

70 to 80 cm away from the 76 cm computer monitor. At this distance the person was able to move their head a total of 70° to 80° (35°- 40° to the right and 35°- 40° to the left of centre).

b) Open-loop tracking (Open Loop with respect to head hereon in referred to as OL): In this predictable cyclic tracking task, only the target (computer) cursor appeared on the screen. (See Figure 7). Participants were asked to rotate the head in concert with motion of the target cursor for 30 seconds. This task did not require continuous foveation to detect a position error.

The computer application generated a logged data file to record coordinates of target cursor and head rotation at 80 Hz for offline analysis of head tracking performance described below.

Participants also were instructed to perform a 30 second walk on a Biodex treadmill at a speed of 0.5 m/s while performing the open loop and closed loop visual tracking tasks. Before beginning this test, participants walked for 1 minute on the treadmill to acclimate to walking on the treadmill.   Figure 8 shows a sample plot of visual tracking output during head rotation with computer reference trajectory.

4.3 Procedure and Task Protocols

This study measured balance while standing on a firm surface, standing on a compliant (sponge) surface and while walking on a treadmill. The test which we called the Dynamic Balance Assessment (DBA) also included two baseline tests performed in sitting. We measured and recorded COP in all four conditions of the mCTSIB as part of our electronic assessment using the FSA pressure mapping system. Linear and angular head movements were recorded using a motion sensor with 6 degrees of freedom of movement (Motion Star, Ascention Tech., USA). Open and closed loop tracking data was collected using a visual tracking system software program during each task when the head was moving.

Sitting Tasks: The subjects were asked to perform OL and CL tracking tasks in sitting using a hand held mouse in order to obtain a baseline reference of their ability to track and follow a moving object at .5 Hz. with eyes only while keeping the head still, with and without continuous foveation. They also performed OL and CL tracking tasks in sitting using the head mounted air mouse to obtain a baseline of their ability to track and follow a moving object using their heads, with and without continuous foveation while their head was moving. These tasks were done 30 seconds each.

Standing tasks on a firm and compliant surface: Testing included standing with eyes open and closed and OL and CL visual tracking. These tasks were performed while standing on the fixed platform of a treadmill with hand rails for safety and on a sponge placed on the treadmill platform. Another person stood behind the participant to ensure no falls occurred during the testing procedure. See Figure 9 for experimental set-up of standing tasks.

mCTSIB: The four conditions of the mCTSIB test were included in the above with eyes open and closed on a fixed and foam surface. Tasks that were not completed due to loss of balance or intense symptoms were marked as incomplete.

Walking tasks on treadmill: Subjects were tested while walking on a treadmill at .5 mi/hr. (.22m/sec. or .8 km/hr) for 30 seconds in both OL and CL conditions after a 1 minute practice. Normal adult walking speeds are around 3.5 feet /sec (2.39 mi/hr or 3.84 km/hr) according to the National Committee on Uniform Traffic Control (LaPlante & Kaeser, 2007). Test speed was set at .5 mi/hr (.8 km/hr) to emulate a slow walking speed that one might perform while moving about slowly inside the home. See Figure 10 for experimental set-up of walking tasks.

Figure 1: ETDRS Eye Chart

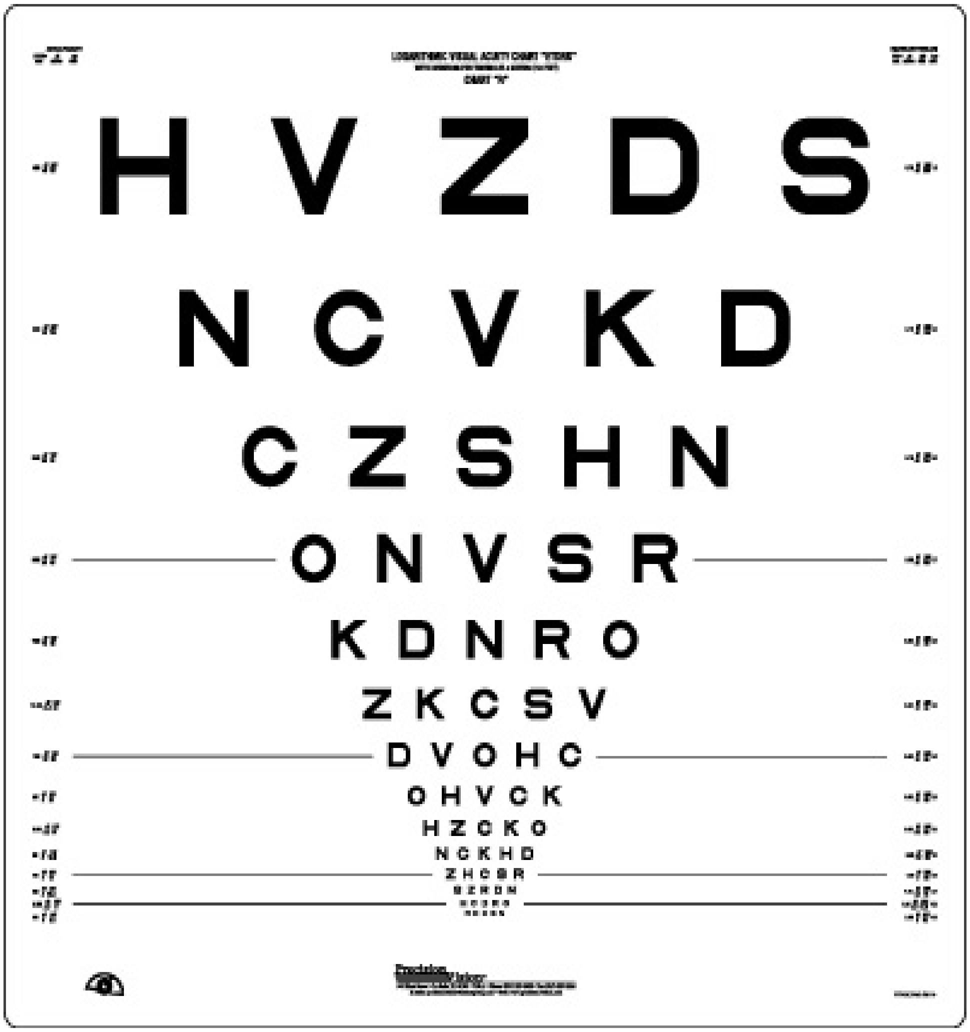
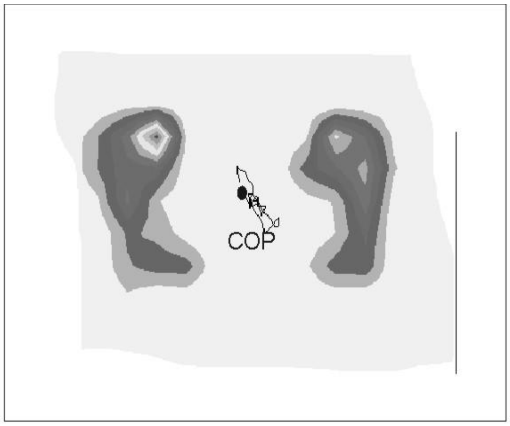
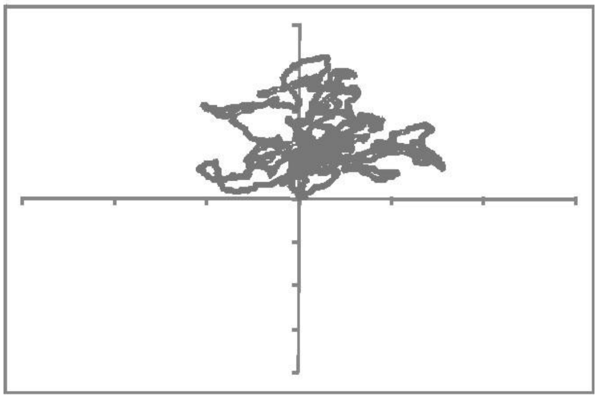


Figure 2: Recording of centre of foot pressure on an FSA mat and COP displacements in anterior-posterior and medio-lateral direction



Snapshot of FSA standing mat profile



COP displacements in AP and ML directions

Force sensor array (FSA) showing a snapshot of centre of foot pressure (COP) on an FSA mat with a representative plot of COP in the anterio-posterior and medio-lateral directions

Figure 3: FSA pressure mat on top of sponge attached to FSA interface

Experimental set-up of Force Sensor Array (FSA) pressure mat on top of sponge attached to the FSA interface.

Figure 4: Motion Star that measures 3D head position and orientation with 6 degrees of freedom

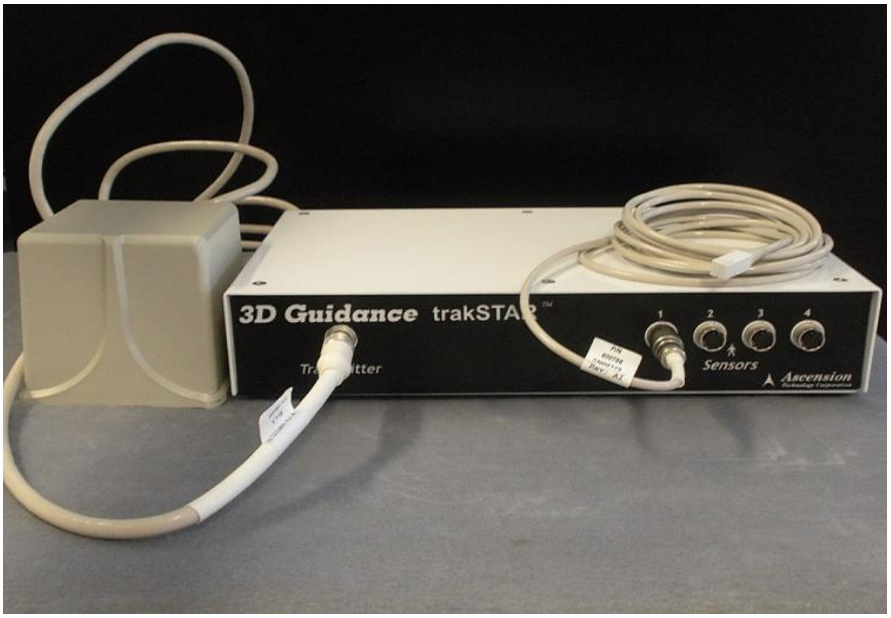
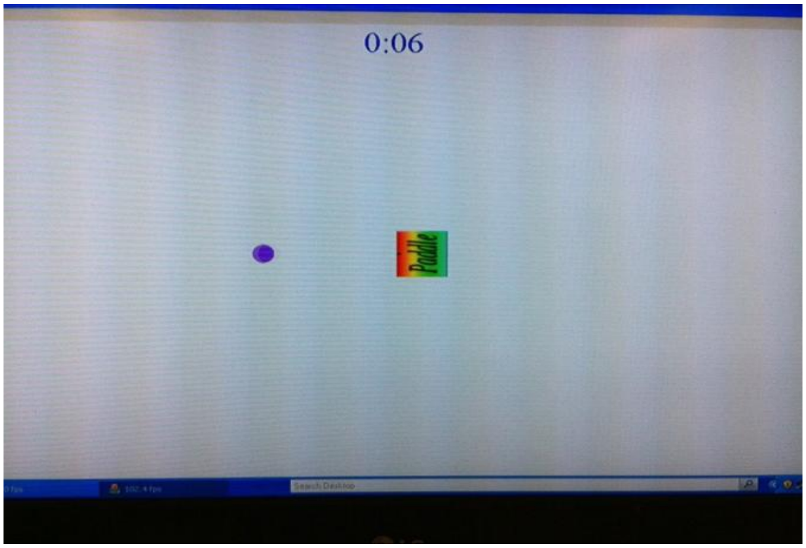


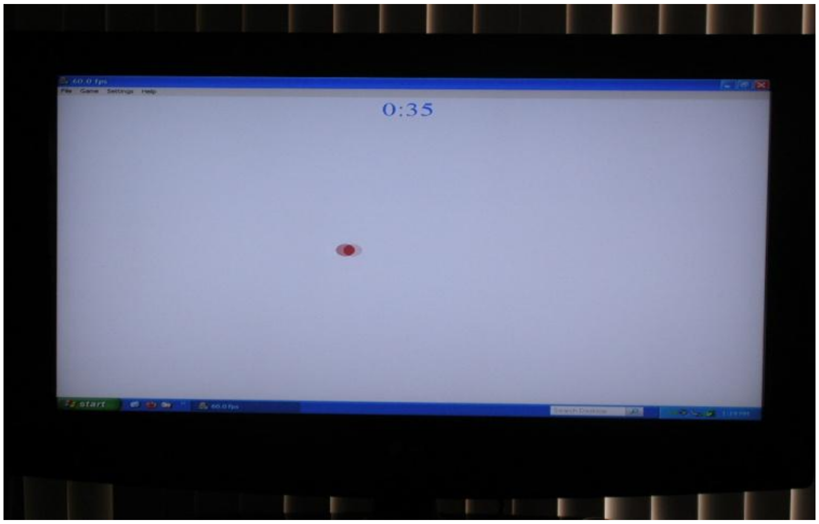
Figure 5: Head mounted air mouse on frame worn on head to move paddle or game sprite

Figure 6: Computer monitor with round computer generated target and paddle controlled by air mouse which is slaved to movement of the head.



Closed loop (CL with respect to the head) visual tracking was performed requiring foveation to overlap the paddle and the computer generated sinusoidally moving target.

Figure 7: Computer monitor with computer generated target. Open Loop (OL with respect to the head).



Open Loop visual tracking was performed requiring minimal foveation to move head in concert with the computer generated sinusoidally moving target.

Figure 8: Recording of visual tracking task and reference trajectory

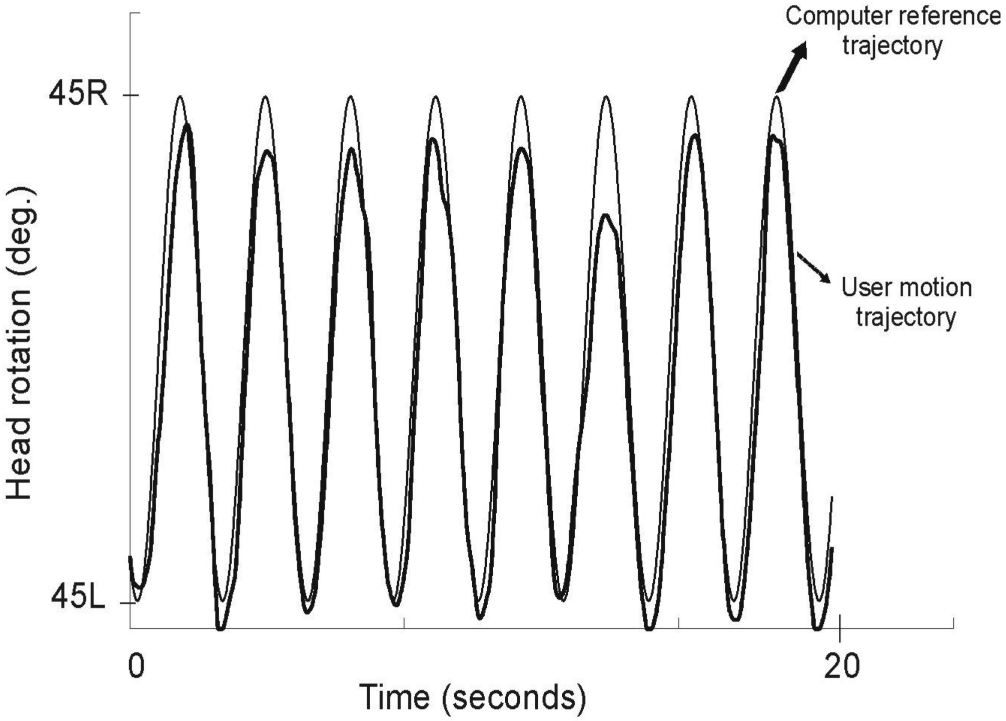


Figure 9: Experimental set-up of subject standing on foam with pressure sensing mat, air mouse and motion sensor worn on top of head while attending to visual tracking task on computer monitor.

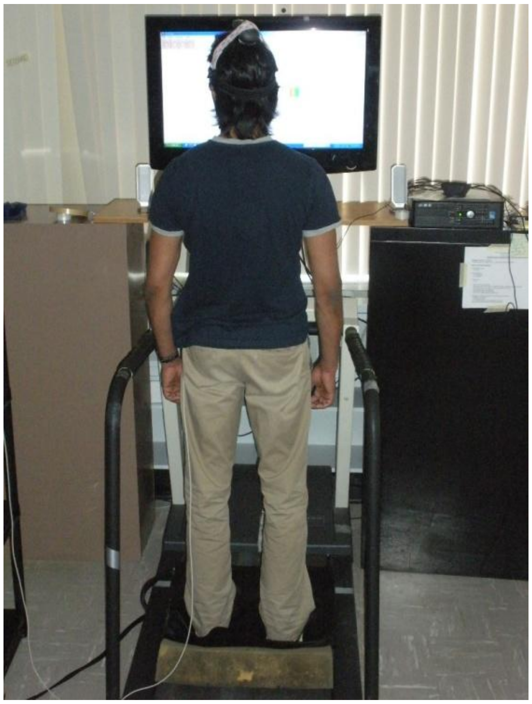


Figure 10: Experimental set-up of subject walking on treadmill while wearing an air mouse and a motion sensor on top of head while attending to tracking task.

Chapter 5:

5.1 Data Analysis:

Linear head motion: Linear head movement measures were recorded during each of the conditions to collect data about position of head in space. This was recorded using a miniature position sensor (Motion Star) that records 6 degrees of freedom of movement. It was attached to the back of the frame that was worn on the head. From this, the average linear peak to peak head movements were computed in the AP and the ML directions, giving an indication of the amount of passive head movement involved in each of the various tasks.

Standing balance measures: Total path length of COP in the ML and AP directions were computed for each task over a 30 second time frame as described by Desai, Szturm, Betker, & Goodman (2010). Increased COP excursion has been interpreted as decreased stability and reduced dynamic balance(A. L. Betker et al., 2005; Lafond et al., 2004). COP scores were obtained for all 8 tasks done in standing on the fixed surface and sponge surfaces: eyes open, eyes closed, open loop and closed loop. The COP scores for mCTSIB (eyes open and closed on fixed and sponge surfaces) was also obtained (Desai, Szturm, Betker, & Goodman, 2010; Giray et al., 2009). The data was conditioned and analyzed using Mat lab version 7 and then validated.

Each test condition was ranked by the evaluating therapist on a scale of 1 to 4, where 1 was a loss of balance, 2 was poor, 3 was fair and 4 was good performance.

Visual tracking Performance Measures: The coordinates of the computer generated cursor (reference target) and the user movements (generated by head rotation and the head mouse) were used to compute the coefficient of determination (COD). The COD represents the quality of the visual tracking tasks as the head rotates where 0.0 represents no correlation between the computer generated reference target and the user movements and 1.0 represents perfect correlation. The upper points on the plot represent the left sided position of the target and the lower points represent the right. The coordinate data of each trial was processed using custom analysis routines written in MATLAB (The Math Works, Natick, MA v.7). The first two cycles were excluded to allow participants time to acquire the moving target and begin tracking. A non-linear least squares algorithm was used to obtain a sine-wave function of the target cursor waveform. User motion trajectories were fitted to the function obtained from the target waveform and COD was determined.

COD was determined under 4 different physical conditions (sitting, standing on a fixed surface, standing on a sponge surface, and walking on a treadmill at .5mph) and under two visual tracking conditions (open loop and closed loop). During each task, the participants ranked the severity of their symptoms from 0 – 10 based on the VAS commonly used in reporting levels of pain where 0 represents no dizziness and 10 represents extreme dizziness.

5.2 Statistical Analysis:

Outliers, as defined by 3 standard deviations from the mean (Rine, 2013), and all tasks that were unable to be completed due to a loss of balance or severity of symptoms were excluded from the analysis.

1. Test retest reliability was measured in 28 of the participants who attended both sessions. Relative reliability of COD and COP between the two sessions was assessed with a paired student t test to determine if there were any systemic errors between the two test periods (Atkinson & Nevill, 1998; Wier, 2005). Relative test-retest reliability was assessed using a two way random effects model ICC (2,1) to determine the COD of visual tracking performance and COP performance between the two sessions. COD scores range between 0 and 1, where 1 represents excellent spatio-temporal accuracy. ICC values were considered to be excellent when >0.75, moderate to good when between 0.4 and .75 and <.4 was considered low to poor (Lexall & Downham, 2005; Shrout & Fleiss, 1979) and while different authors may vary in their definition of what is a good score, overall, the closer the score is to one, the better the score (Riddle & Stratford, 2013). The standard error of measurement (SEM) was used to determine absolute reliability and within-client variance or variability between the two test sessions. SEM was calculated using the formula: SEM = SD x $\sqrt{1-ICC}$
where SD is the average SD of the two test session scores (Wier, 2005). The SEM is helpful clinically in determining within what range a person's true score lies in and if the score is valid. The coefficient of variation of the SEM referred to as SEM% was represented as SEM/pooled means of test 1 and 2 x 100 and provided a standardize method of comparing measurement error between the various tests (Adsuar, Olivares, Parraca, Hernández-Mocholí, & Gusi, 2012; Mohammad et al., 2011; Wang, Sheu, & Protas, 2009).

2. Convergent validity of the new assessment tool was evaluated using Spearmans rank order correlation co-efficient (rho) to determine the strength of association of the new tool and the clinical tests believed to measure the same attribute. Spearman's rho values were used for this part of the analysis because the new assessment was correlated to clinical tests which used an ordinal scale of measurement (Finch et al., 2002). It was used to determine the strength of the relationship between performance measures of COP, COD and the clinical measures of the DHI, DGI and the DVA scores. In Spearmans correlation coefficient the closer the rho value is to 1, the stronger the correlation where >0.6 is considered strong, 0.31 to 0.59 is fair to moderate and ≤0.3 is poor to low. (Alia A. Alghwiri, 2012). .

3. Construct validity looked at the effects that:

(a) physical demands (which included different surface types, standing and walking tasks) had on visual tracking performance as measured by COD.

(b) visual conditions (which included eyes open and closed conditions and open and closed loop tracking conditions) had on balance performance as measured by COP and visual tracking performance as measured by COD.

This was done using a one-way repeated measures ANOVA. Post Hoc analysis using Bonferonni correction was done to show how the means differed from each other. Partial eta squared was determined as a measure of effect size. Statistical significance was set at 0.05 (two-tailed) and analyzed in Statistical Package for Social Science (SPSS) software for Windows, Version 20.0 (SPSS Inc. Chicago, IL,USA). Descriptive statistics were calculated for normally distributed variables using group means ($\bar{X}$) and standard devitions (SD).

Chapter 6: Results:

6.1 Reliability:

A total of 30 people with vestibular disorders participated in this study. 28 people returned to complete the retest portion of the protocol. Demographic Data was collected regarding age, sex, vestibular diagnosis and medications was collected. See Table 1.

The extent of vestibular dysfunction ranged from minor loss (23%) to complete and profound bilateral loss. This resulted in a large variance in task performance as measured by SD and frequent loss of balance (LOB) especially under the more difficult conditions. This reduced the sample size for COP. The LOB was most noticeable while on the sponge surface, especially with vision removed, particularly for those with bilateral vestibular loss. This is consistent with what has been recorded elsewhere (Desai, 2012). Due to the low number of people who completed this task successfully, we were unable to use Eyes Closed Sponge (ECS) in the analysis. See Table 2.

Therapist consistency of ranking between test 1 and test 2 was excellent (ICC=.93).

Group means and Standard Deviations for linear AP and ML head motion were collected from the motion star tracking system and passive head movements were determined. Mean peak to peak head movement in the AP direction ranged from 4.18 cm in OL sitting to 4.92 cm in CL walking for a difference of < 1.0 cm. When there was no head movement involved, that is, with eyes open with head still on a fixed or sponge surface, mean linear peak to peak AP movement was1.1 and 1.2 cm respectively. Peak to peak head movement in the ML direction ranged from 5.60 cm in OL sitting to 17.81 in

OL walking. The contribution of passive head motion in the AP direction remained small even while the head was actively moving in a ML direction during OL and CL conditions (less than 4.18 cm in sitting to 4.9 cm while walking), however the peak to peak ML ranged from 5.6 cm in sitting to 17.82 cm during OL and CL conditions while walking with a threefold increase in passive head movement. See Table 3.

Test retest reliability for Balance:

COP excursion and total path length in standing on the fixed and sponge surfaces was used to index standing balance. Generally it was noted that subjects did better on the second test than on the first. The ICC scores for test retest reliability of COP demonstrated good to excellent in both AP direction and ML direction in all conditions ranging from .71 and .89 in the AP direction from .64 to .90 in the ML direction which is good to excellent. When the eyes were open on sponge condition with no head movement, ICC's in both AP and ML directions were the most similar and highest (.89 and .90). ICC's were lower when the eyes were closed or when head movement was introduced. Based on the t test, there were no systemic errors between the test 1 and test 2. The SEM scores and SEM% and the group means for COP between test 1 and test 2 were smallest when the eyes were open and the heads still on the sponge and during closed loop on the fixed surface in the AP and ML directions. They became larger as the task increased in difficulty and were largest when the eyes were closed on the fixed surface and during open loop on the sponge surface in the AP and ML directions. As the task became more complex and harder to do, the SEM, SEM% and the group means became larger compared to the easier tasks. See Tables 4 and 5 for ICC values for COP in AP and ML directions for standing on fixed and sponge surfaces.

Test retest reliability for visual tracking:

COD was analyzed in standing on a fixed surface, a sponge surface and while walking on a treadmill. The ICC scores for COD showed good to excellent test retest reliability for open and closed loop on fixed surface and closed loop on sponge and treadmill (ICC=.61 to .75), low reliability for open loop on the sponge (ICC=.46) and showed poor significance for COD open loop condition on the treadmill ICC=.33). The t test for this test showed a significant difference between test 1 and test 2. The SEM for open loop tracking on the treadmill was large (.15). A 95% confidence interval (CI) for this score can be calculated using the z value: (SEM x 1.96) ± obtained score. In this instance, the 95% CI for SEM in open loop treadmill COD is .15 x 1.96 ± .63 = (.33, .92) which is the range within which the true value will fall. This is a very large range which explains why the test was not significant. The scores fall with a range of having poor to excellent significance at the same time which has very little meaning. For COD, the SEM % increased as the physical load increased and was highest on the treadmill. Clinically, once the SEM of a specific population or person for a specific test condition has been determined after multiple tests , it can be useful in determining if a measured score falls within an acceptable level of reliability (Riddle & Stratford, 2013). See table 6 for ICC values of COD.

Figures 11 to 13 show test retest group means and standard deviation of COP and COD: Figure 11 shows sway path length (SPL) for medial-lateral (ML) centre of pressure (COP) excursion, Figure 12 shows SPL for anterior-posterior (AP) COP excursion and Figure 13 shows test-retest group means and standard deviations for COD of Open Loop (OL) and Closed Loop (CL).

Table 1: Demographic and Participant data

Age, (years), $\bar{X}$ (SD) range	47.7 (9.84), 26-66
Sex, n	
Male	11
Female	19
Chronicity of symptoms (months), $\bar{X}$ (SD)	31.66 (28.04)
Range (mo), median (IQR)	6-120, 24 (27)
Unilateral Hypofunction	20
Bilateral Hypofunction	10

Table 2: Number of incomplete tests first and second visit due to loss of balance or dizziness

Variables	Did not complete test 1 (N,30)	Did not complete test 2 (N,28)
Eyes open fixed	0	not part of protocol
Eyes open sponge	3	0
Eyes closed fixed	6	3
Eyes closed sponge	20	17
Open Loop fixed	4	0
Closed Loop fixed	1	0
Open Loop sponge	5	3
Closed Loop sponge	3	3
Open Loop treadmill	7	3
Closed Loop treadmill	6	2

Table 3: Group means and SD's for AP and ML linear head movement

Motion Star Peak to Peak Linear Head movement in mm				
	AP $\bar{X}$	AP SD	ML $\bar{X}$	ML SD
Open Loop Sitting	41.8	58.7	56.0	68.7
Closed Loop Sitting	48.1	66.9	67.2	91.5
Eyes Open Fixed Surface	11.4	14.4	40.5	37.1
Eyes Closed Fixed Surface	46.5	11.8	67.4	65.4
Eyes Open Sponge Surface	12.4	11.6	46.3	26.9
Eyes Closed Sponge Surface	28.8	23.1	147.2	92.9
Open Loop Fixed Surface	32.9	58.4	63.6	72.4
Closed Loop Fixed Surface	30.7	46.9	65.6	60.8
Open Loop Sponge Surface	41.7	64.9	82.4	73.6
Closed Loop Sponge Surface	37.6	58.9	93.3	83.4
Open Loop Walking on Treadmill	48.1	53.9	178.2	87.9
Closed Loop Walking on Treadmill	49.2	75.5	167.7	96.7

Table 4: ICC and SEM of COP excursions in AP directions for different surface and visual conditions

COP EXCURSION Sway Path Length in AP direction (cm)	ICC (95% CI)	Mean ± SD Test 1	Mean ± SD Test 2	SEM SEM (%)	t statistic (df, p value)
COP EC Fixed	.74 (.42-.90)	3.4 ± 2.1	3.1 ± 1.8	2.0 61.3%	.68 (16, 51)
COP OL Fixed	.71 (.40-.87)	2.5 ± 1.0	2.5 ± 1.6	0.7 28.3%	.003 (19, 1.0)
COP CL Fixed	.80 (.56-.91)	2.4 ± .90	2.4 ± 1.1	0.4 18.7%	.73 (19, .47)
COP EO Sponge	.89 (.73-06)	2.2 ± 1.1	2.2 ± 1.1	0.4 17.1%	-.12 (18, .85)
COP CL Sponge	.74 (.50-.89)	3.3 ± 2.5	2.8 ± 1.5	1.0 33.0%	1.40 (18, .07)
COP OL Sponge	.76 (.49-.89)	2.6 ± 3.3	3.5± 2.5	1.2 46.6%	1.94 (22, .18)

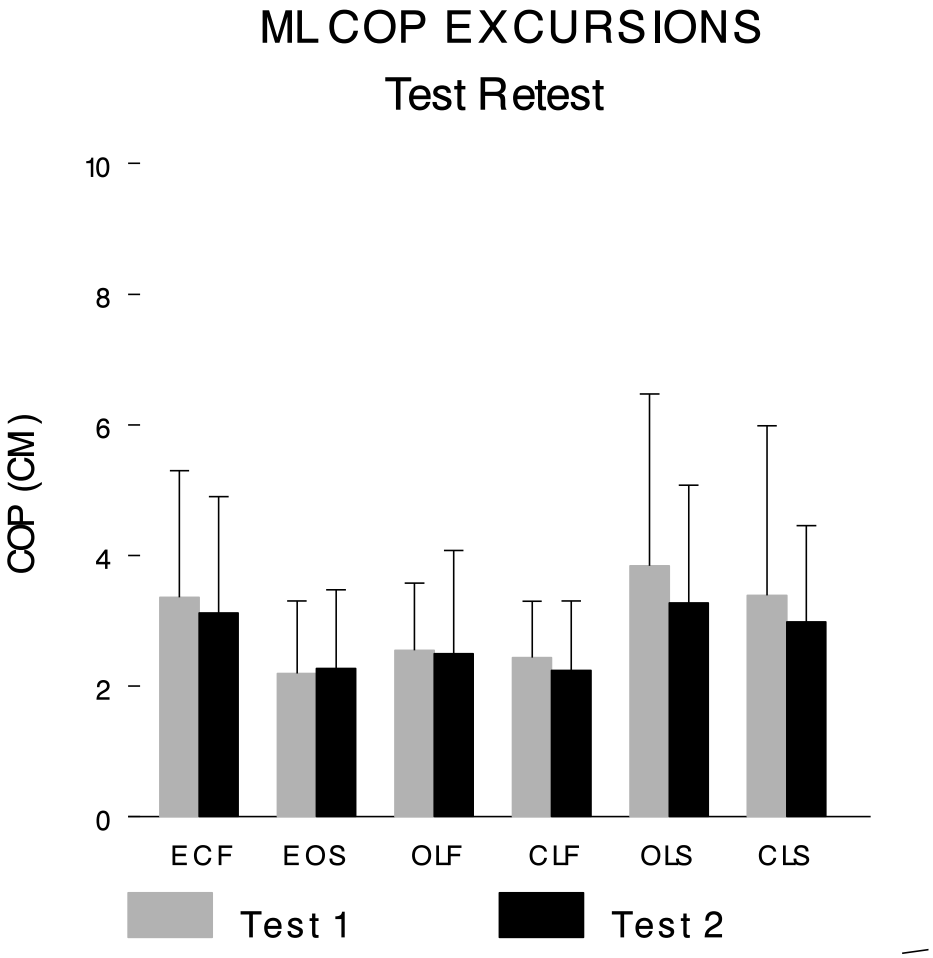
COP: centre of foot pressure; ICC: intraclass correlation coefficient; SEM: standard error of measurement; CI: confidence interval; SD: standard deviation; COV: coefficient of variation; df: degrees of freedom; AP: anterioposterior; EC: eyes closed; OL: open loop; CL: closed loop; EO: eyes open

Table 5: ICC and SEM of COP excursions in ML directions for different surface and visual conditions

COP EXCURSION Sway Path Length in ML (cm)	ICC (95% CI)	Mean ± SD Test 1	Mean ± SD Test 2	SEM (cm) SEM%	t statistic (df, p value)
COP EC fixed	.64 (.24-.86)	3.4 ± 1.9	3.1 ± 1.8	1.1 34.4%	.60 (16, .56)
COP OL fixed	.70 (.38-.87)	2.6 ± 1.0	2.5 ± 1.6	0.7 28.3%	.21 (19, .83)
COP CL fixed	.69 (.38-.87)	2.4 ± 0.9	2.2 ± 1.1	0.5 22.8%	1.16 (19, .30)
COP EO Sponge	.90 (.76-.96)	2.2 ± 1.1	2.3 ± 1.2	0.3 12.4%	-0.70(18, .49)
COP CL Sponge	. 67 (.31-.85)	3.4 ± 2.6	3.0 ± 1.5	1.2 37.5%	1.02 (18, .32)
COP OL Sponge	. 89 (.75-.95)	3.8 ± 2.6	3.3 ± 1.5	1.5 42.1%	1.62 (22, .12)

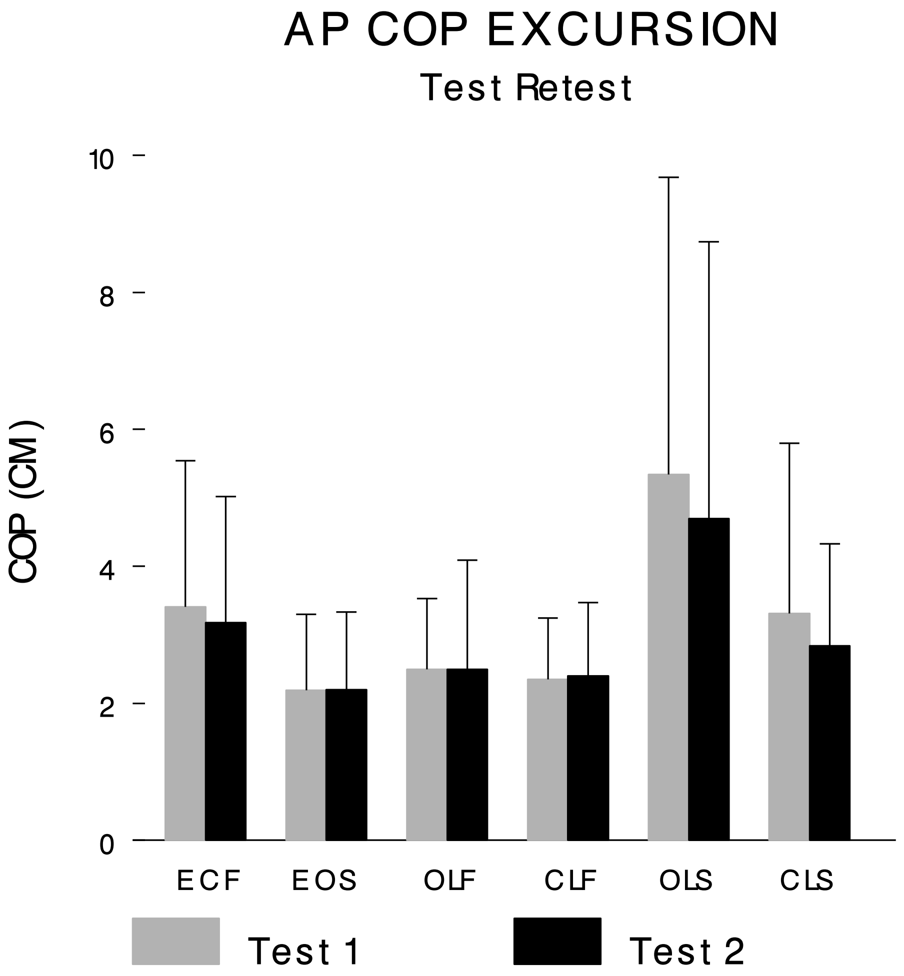
COP: centre of foot pressure; ICC: intraclass correlation coefficient; SEM: standard error of measurement; CI: confidence interval; SD: standard deviation; COV: coefficient of variation; df: degrees of freedom; ML: mediolateral; EC: eyes closed; OL: open loop; CL: closed loop; EO: eyes open

Figure11: Test retest for group means and SD for COP sway path length in medio-lateral COP



Test 1 and 2 group means and standard deviations for ML COP excursion test 1 and test 2. ML: medio-lateral, COP: centre of pressure, ECF: eyes closed fixed, EOS: eyes open sponge, OLF: open loop fixed, CLF: closed loop fixed, OLS: open loop sponge, CLS: closed loop sponge

Figure 12: Test 1 and Test 2 group means and SD for COP sway path length in anterio-posterior direction



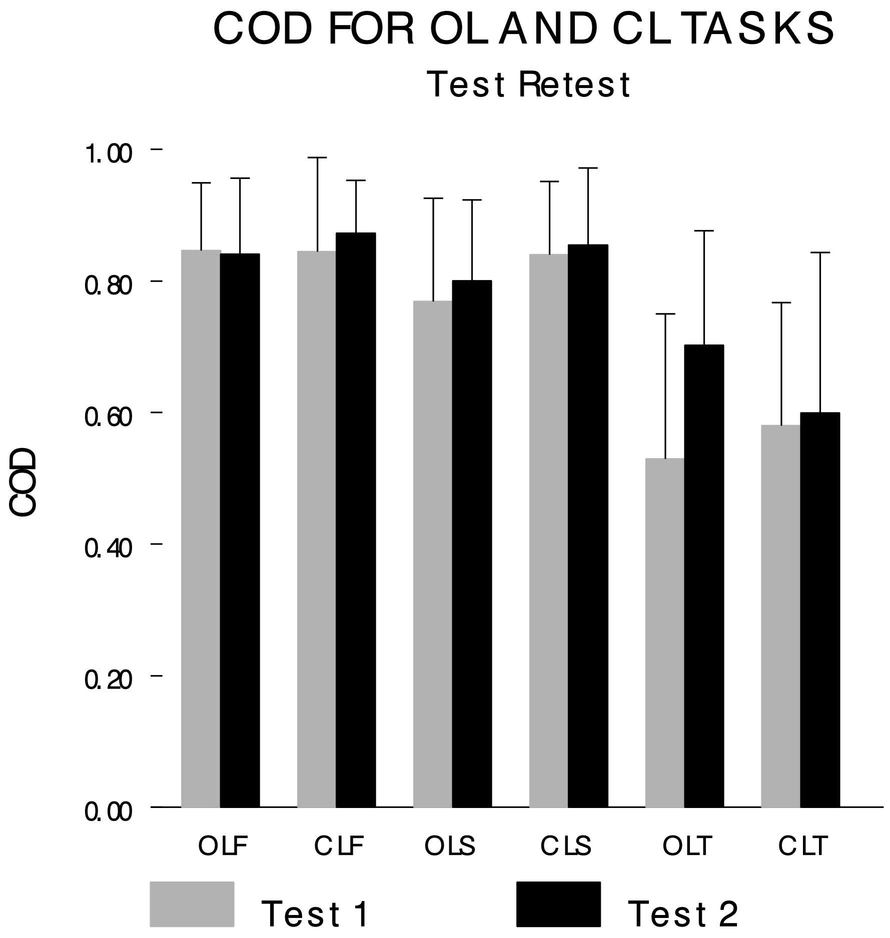
Test 1 and 2 group means and standard deviations for AP COP excursion test 1 and test 2. AP: anterior-posterior, COP: centre of pressure, ECF: eyes closed fixed, EOS: eyes open sponge, OLF: open loop fixed, CLF: closed loop fixed, OLS: open loop sponge, CLS: closed loop sponge, TPL: total path length

Table 6: ICC and SEM of COD under different surface and visual conditions

COD	ICC (95% CI)	Means±SD Test 1	Mean±SD Test 2	SEM SEM %	t statistic (df, p value)
COD OL Fixed	.75 (.52-.88)	.85±.10	.84±.12	.06 6.5%	.35 (25, .73)
COD CL Fixed	.607 (.32-.80)	.85±.14	.87±.08	.07 8.2%	-1.46 (24, .16)
COD OL Sponge	.46 (.07-.73)	.77±.16	.80±.12	.10 13.0%	-1.01 (21, .32)
COD CL Sponge	.75 (.51-.88)	.84±.11	.85±.12	.06 6.9%	-.89 (23, .38)
COD OL Treadmill	.33 (-.19-.70)	.55±.19	.70±.17	.15 23.8%	-2.79 (22, .01)
COD CL Treadmill	.71 (.41-.87)	.60±.16	.62±.13	.08 12.8%	-.1.16 (19, .26)

COD: coefficient of determination; ICC: intraclass correlation coefficient; SEM: standard error of measurement; CI: confidence interval; SD: standard deviation; COV: coefficient of variation; df: degrees of freedom; AP: anterior-posterior; EC: eyes closed; OL: open loop; CL: closed loop; EO: eyes open

Figure 13: Test 1 and 2 group means and standard deviation for coefficient of determination (COD) for open and closed loop tasks under different physical conditions



Coefficient of determination for open and closed loop tasks under different physical conditions for test 1 and 2. SD: standard deviation, COD: coefficient of determination, OL: open loop, CL: closed loop, OLF: open loop fixed, CLS: closed loop fixed, CLS: closed loop sponge, OLT: open loop treadmill, CLT: closed loop treadmill.

Convergent Validity:

Convergent Validity was evaluated using Spearman's rank correlation coefficient (rho). The Dynamic Gait Index, the Dynamic Visual Acuity Test and the Dizziness Handicap Inventory Questionnaire were analyzed and compared to computerized scores, which are believed to measure the same attributes, of the COP on fixed and sponge surfaces and COD scores of open loop and closed loop in sitting, while standing on a fixed and sponge surface and while walking on the treadmill. There were no clinically useful correlations between DVA, DHI and DGI and COP in standing and walking conditions. There was only a weak correlation between the DGI and the OL COD condition on the treadmill (rho=.38). No clinically useful correlation was made between the DHI which is a perception of one's own dizziness and the subjects own ranking of their dizziness using the visual analogue scale (0-10) during the testing procedure. There was no significant correlation between the therapist's ranking of balance performance and COP scores (rho= -.20). See Table 7 for Spearmans correlation coefficient for comparisons between COP and COD and clinical measures. See Table 8 for Spearmans correlation coefficient for comparisons between self ranking of subject's dizziness (using VAS) during the testing and DHI score.

Table 7: Spearmans correlation coefficient for comparisons between composite COP and COD measures and Clinical measures

Variable	cCOP ML fxd	cCOP AP fxd	cCOP ML spng	cCOP AP spng	COD CL fxd	COD OL fxd	COD CL spng	COD OL spnge	COD CL trdml	COD OL trdml
DGI	-.14	-.28	-.34	-.34	.36	.17	.22	.27	-.12	.38
DVA	-.24	-.20	-.11	-.12	.12	.29	.17	.24	.14	.20
DHI	-.05	.07	-.19	-.14	0.0	-.18	-.27	-.32	-.12	-.04

COP: centre of foot pressure; COD: coefficient of determination; OL: open loop; CL: closed loop; cCOP composite centre of foot pressure (for eyes open, eyes closed, open loop, closed loop); ML: medio-lateral; AP: anterior-posterior; fxd: fixed; spng sponge; trdml: treadmill; DGI: Dynamic Gait Index; DVA: Dynamic Visual Acuity Test, DHI: Dizziness Handicap Inventory

Table 8: Spearmans correlation coefficient for comparisons between self ranking of subject's dizziness during the testing of Visual Analogue Scale and Dizziness Handicap Inventory score

DHI and subject self ranking	Spearman's rho value
Open loop and closed loop fixed, sponge and treadmill composite	.22
Open loop and closed loop fixed composite	.29
Open loop and closed loop sponge composite	.13
Open loop and closed loop treadmill composite	-.12

Construct Validity:

Physical Load

One-way repeated ANOVAs were done to determine how changing the physical demands of the task affected gaze performance and foveation. There was a decrease in both OL and CL COD that became statistically significant at the treadmill level. Changes in COD between the chair, fixed surface and sponge were not statistically significant. Post hoc Bonferonni correction was applied to evaluate the relationship between the physical tasks and the COD. This demonstrated a statistically significant decrease ($p<.0005$) in COD on the treadmill as compared to sitting and standing on the fixed or foam surfaces in both open loop and closed loop conditions. There was a significant effect of surface conditions on COD [$F(2,76)=10.35$, $p<.009$ partial eta squared .353] in the open loop condition and [$F(1.928,36.639)=25.296$, $p<.001$, partial eta squared .571] in the closed loop condition when compared to eyes open head still on the sponge. COD, which represents smoothness and quality of visual tracking performance, was significantly lower while walking on the treadmill for both CL and OL when compared to sitting or standing on different surfaces. Visual performance, as measured by COD was also decreased on the sponge when head rotation was added during open loop and closed loop tracking conditions. Balance performance as measured by COP was not significantly affected on the fixed surface by increases to physical load, however there was a significant effect of physical load on balance performance seen on the sponge when head rotation was introduced during open and closed loop tracking conditions. See table 9. Figure 14 shows the effect of physical conditions and visual load on visual tracking performance as measured by COD.

Visual Load: A one-way repeated ANOVA was done to determine how changing the visual demands of the task affected balance performance and sway path length as measured by COP on different surfaces. There were no significant effects of visual conditions in open loop, closed loop, eyes open and eyes closed after Bonferonni correction was applied to COP while standing on a fixed surface [F(2.188,48.137)=3.209, p<.045, partial eta squared =.127].

The same tests were repeated on a sponge surface. COP on the sponge with eyes closed was significantly greater than the COP with eyes open p<.01 but due to the low number of people that were able to complete the test with eyes closed (n,10), the analysis was repeated without the eyes closed condition (n,23). COP increased significantly as the task became harder with head rotation from eyes open head still to open loop (p=.003) and closed loop conditions (p=.008). [F(2,44)=9.938, p<.0005, partial eta squared .311]. No statistically significant difference was found on the fixed surface under different visual conditions but as the surface demands and complexity of the task increased on the sponge, a statistically significant change was found. The main effect of visual load on balance performance was on the sponge when head rotation was performed during open and closed loop conditions. See Table 9. Figure 14 shows the effect of changes to the physical load and visual load as measured by COP in ML direction.

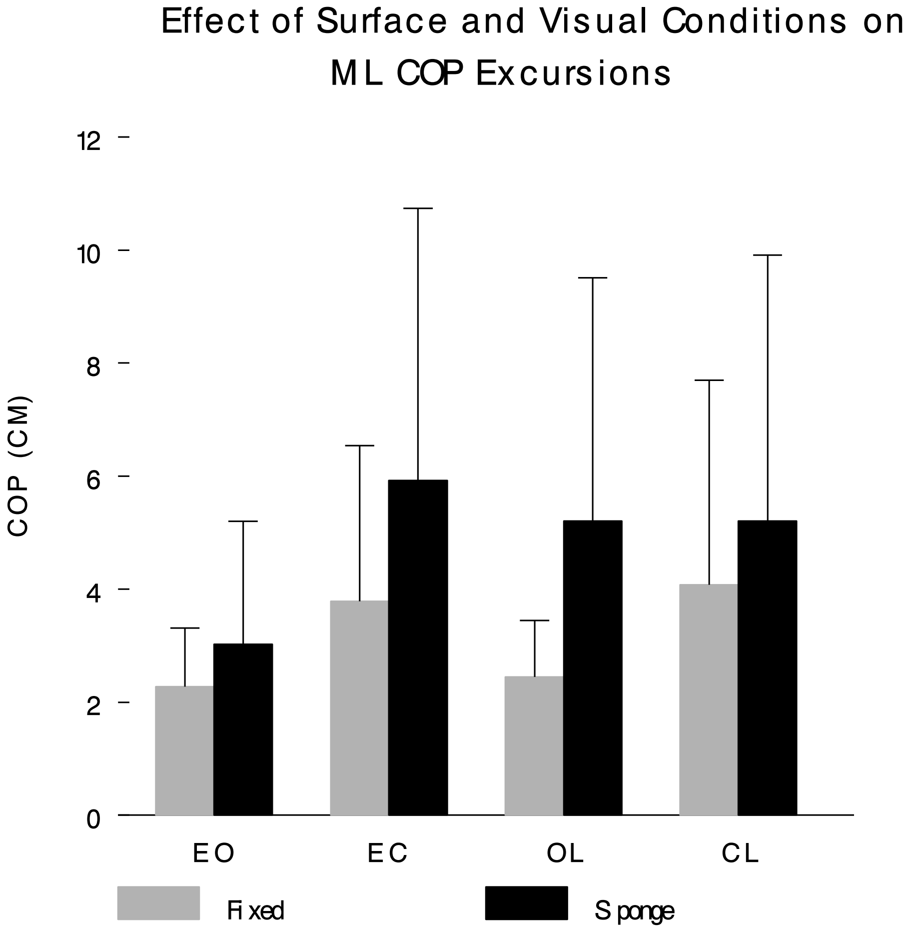
COD decreased significantly on the treadmill as the visual load increased. As the task became harder from open loop to closed loop condition, the significance dropped from p<.009 in OL to p<.001 in CL condition as shown in table 10. Figure 15 shows the changes to COD as the visual and physical load increased.

Balance performance decreased on the sponge when the eyes were closed as noted by the large number of losses of balance. It also decreased during head rotation in open and closed loop conditions as compared to eyes open on the sponge. Visual tracking performance decreased with additional visual loads and on the treadmill. As the task became harder from open loop to closed loop, the performance decreased. This is consistent with the hypothesis.

Table 9: One way Repeated ANOVA for balance measures (COP) on visual load during eyes open, eyes closed, OL and CL conditions and visual measures (COD) on visual load

Variable	Visual Load	Post hoc Bonferonni Correction
COP Fixed surface	$p<0.045$ F=3.209 (2.188,48.137) Huyn-Feldt Correction Partial eta squared .127	Not significant effect size
COP Sponge Surface (no ECS)	$P<0.0005$ F=9.938 (2,44) Partial eta squared .311	EOS and OL Sponge significant $p=.003$ EOS and CL sponge significant $p=.008$

Figure 14: Effect of changes to the physical load and visual load as measured by COP in ML direction

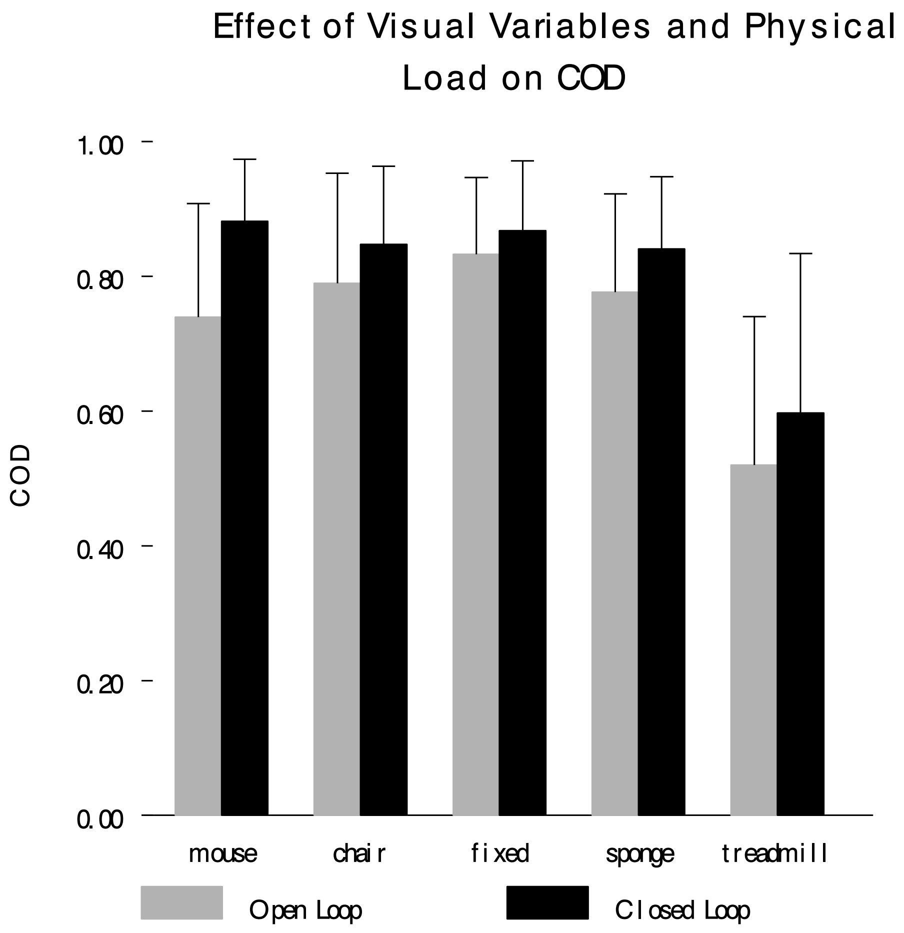


Effect of increasing the physical and visual loads as measured by COP. COP: centre of pressure, ML: medio-lateral, EO: eyes open, EC: eyes closed, OL: open loop, CL: closed loop

Table 10: One way Repeated ANOVA for tracking performance measure (COD) on physical load while sitting mouse only (no head), sitting with head movement, standing on a fixed surface, a sponge surface and while walking:

Variable	Physical Load	Post hoc Bonferonni Correction
COD (Open Loop)	p<.0005. F=10.35 (2,76) Partial eta squared .353	OL COD p<.009 on treadmill
COD (Closed Loop)	p<0.0005 F=25.30 (1.928,36.639) Huynh-Feldt Correction Partial eta squared .571	CL COD p<.001on treadmill

Figure 15: Effect of physical conditions and visual load on visual tracking performance as measured by COD.



Effect of physical conditions and visual load on visual tracking performance as measured by coefficient of determination (COD).

Chapter 7: Discussion and Conclusion:

The vestibular system plays an important role in maintaining balance and gaze control during walking and functioning in the natural environment. When it is damaged from disease, injury or aging, balance becomes difficult to maintain. Not only is the motor control system affected, symptoms of dizziness and visual disturbances result in decreased mobility and an increased risk of falling. The purpose of this study was to assess the reliability and validity of a new computerized method of assessing balance and gaze control under a broad range of physical and visual conditions in a population of people with vestibular hypofunction.

7.1 Main findings:

Test retest reliability for balance performance as measured by COP was found to be moderately good to excellent. Visual tracking performance as measured by COD was moderately good to excellent for all conditions except for open loop visual tracking on the sponge and treadmill. No clinically useful correlations were found between clinical performance-based tests of balance and visual acuity (DHI and DVA) and the computerized tests of balance and visual tracking performance. No clinically useful correlation was made between the DHI and the subjects own ranking of their own dizziness. Balance performance decreased on the sponge surface when head rotation during OL and CL were introduced. Visual tracking performance decreased significantly on the treadmill as the visual load increased. This coincided with a large increase in passive head movement.

7.2. Reliability:

Two recent studies have measured dynamic visual acuity (DVA) using computerized methods (Mohammad et al., 2011; Rose Marie Rine et al., 2012). Mohammad et al. (2011) examined static visual acuity (SVA) and DVA using two different tests in a sample of 29 people with vestibular hypofunction. Testing was done in sitting and dynamic visual acuity was measured using two different testing methods. The GST measured DVA with horizontal head rotations at velocities that were gradually increased from 124°/s to 152°/s while the optotype remained the same size. The second method examined the cDVA and required subjects to identify a stationary optotype that decreased in size during active horizontal head rotations at velocities between 85°/sec and 120°/sec. SVA scores were excellent between the 3 sessions ranging between .78 and .88. During the GST part of the study with head velocities between 124°/s to 152°/s, the ICC scores were poor to fair, ranging from 0.0-.48. During the cDVA test with slower head velocities of 85°/s to 120°/s, ICC scores improved, ranging from .64 to .83.

In a large study by Rine et al. (2012) with 318 participants including children and adults, sponsored by the National Institute of Health (NIH), reliability of the SVA and DVA was tested. There were 54 adults in the study aged 18 to 75 and included those without vestibular pathology (n=48) and those with vestibular pathology (n=6). They were tested in sitting. The ICC scores for SVA was .81, similar to the Mohammad (2011) study. DVA was then tested with active head rotations of ≥180°/s using the cDVA. Right and left sides were tested separately and the average ICC score for the two sides was .58. The breakdown of ICC scores between those with and those without pathology was not provided. Another limitation of this study was the low number of people with vestibular pathology. The data was unable to show with any power the differences between those with and without vestibular disease due to the low number of people with vestibular dysfunction. Both the Mohammad study (2011) and Rine study (20012) showed that as the task became harder with added head rotation and increased head velocities, the ICC scores for test retest reliability decreased.

In the present study, ICC scores for visual tracking performance as measured by COD were consistent with the above scores that used cDVA test except that the test was not repeated in sitting. The previously mentioned studies that examined visual acuity in sitting used active head velocities which for the most part exceeded 100°/s whereas the present study examined gaze at slower head velocities of .5 Hz and approximately 70°/s to 80°/s. At velocities below 100°/s, the smooth pursuit system is able to assist in maintaining the image on the fovea while tracking a moving object and may have acted to assist with the visual tracking task, especially in the closed loop conditions which showed higher ICC values (Meyer, Lasker, & Robinson, 1985). .

In the studies that looked at cDVA (Mohammad et al., 2010; Rine et al., 2012; Rine et al., 2013), visual acuity was higher when the head was static and decreased when the head was moving. Visual acuity was not examined while standing on different surfaces or walking. Walking is a very functional activity that people with vestibular hypofunction often have difficulty with and passive head motion is another important factor that must be considered during walking as it challenges gaze stability (Hillman, Bloomberg, McDonald, & Cohen, 1999; Scherer, Migliaccio, & Schubert, 2008). In the present study, there was minimal passive linear head motion that occurred while sitting, standing and in the AP direction of walking however there was a 400% increase in linear head movement that occurred in the ML direction of walking on the treadmill not seen in the other conditions. This very large increase in linear head movement seen while walking may have influenced the consistency and reliability between test 1 and 2 and affected the ICC scores. The ability to maintain fixation of a target on the fovea is easier to do when the target is stationary and becomes harder when the target is moving. It is also easier to maintain fixation when the target is moving predictably rather than unpredictably. As the amount of unpredictable movement increased, there was a corresponding decrease in tracking performance as measured by COD. The increase in unpredictable head movement seen during OL walking may have contributed to the difficulty in stabilizing gaze with smooth pursuit and accounted for the corresponding lack of reliability. With no need to coordinate the head movement with the computer generated target during OL, the increase in passive head movements that were recorded while walking resulted in wide variances with low correlation. Similarly, while standing on an unstable support surface such as the sponge, passive head motion increased and reliability of visual tracking performance was reduced. As the tasks became more complex, the ICC scores became lower and the percentage of measurement error (SEM%) increased.

COD is a measure of the smoothness and coordination of the head movement. CL tracking requires continuous foveation to identify error in position of the head mounted cursor relative to the target as it moves left and right. During the CL conditions where there was visual feedback of the head position relative to the target and high levels of continuous foveation, ICC scores were higher on the sponge and treadmill. In the OL tasks, no overlap of targets was required and no information was provided regarding head position relative to the target which may have resulted in the lower ICC scores in the same conditions. Studies have shown that concentrating on a visual target helps patients with vestibular disorders stabilize head position in space during gait (Diehl & Pidcoe, 2010; Mu`lavara & Bloomberg, 2003; Redfern, Yardley, & Bronstein, 2001; M. Schubert, Bohner, Berger, Sprundel, & Duysens, 2003) and this too may have lead to higher ICC scores for CL movements in walking.

Patients with peripheral vestibular disease have a deficient VOR causing retinal image slip on the fovea and difficulty in maintaining gaze stability and visual acuity during head movement resulting in a decrease in a visual resolution and an increase in visual blurring. Barnes (2008) noted that smooth pursuit, important in tracking a moving object, helps reduce retinal slip by maintaining the image on the fovea where high visual resolution takes place. When the head moves, the smooth pursuit system, together with the optokinetic reflex system, saccadic eye movements and the VOR, assist with the process of decreasing retinal slip. A deficient or absent VOR during head rotation results in retinal image slip and blurring of vision, oscillopsia, nausea, imbalance and feelings of disorientation (Land, 2006; M. C. Schubert, Migliaccio, Clendaniel, Allak, & Carey, 2008).

As precision decreases with the unpredictability of passive movements in gait, variability between tests increases and reliability is reduced. Yu, Yank, Villard, & Stoffregen (2010) in their study of sailors in rough sea conditions found that visual performance decreased as passive movements were increased. In the current study, when subjects were walking, test measures were more reliable and performance was more consistent in the CL condition where a high level of continuous foveation and visual feedback with respect to head position was provided. The low ICC score during the OL task may have been due to decreased smooth pursuit, increased retinal slip and decreased precision of movements from reduced foveation caused by increased passive head motion. As the visual tasks became harder and the amount of unpredictable and passive movements increased from standing still to walking, it became more challenging to maintain continuous foveation. Maintaining gaze stability while walking requires the head to be stabilized on the trunk (Hillman et al., 1999). This becomes very difficult for people with vestibular dysfunction, especially when movements of the head become unpredictable. During CL walking, visual feedback with respect to head position from the head mounted cursor provided additional information about velocity error. This feedback was not available during OL walking resulting decrease visual acuity and greater recorded error.

Another explanation for the lack of reliability and the large variation in measurements between test 1 and 2 of OL walking may have been due to a learning effect which was not evident with the other conditions.

COP excursion as determined by total sway path length has been shown to be a reliable outcome measure for indexing balance (Lafond et al., 2004). The present study used COP to measure balance in people with mild to profound vestibular loss. The ICC values for COP excursion in the present study were good to excellent in all conditions in both AP and ML directions except for eyes closed on the sponge where two thirds of the study participants lost their balance. Too few people completed the test to do an analysis of this condition. People with vestibular dysfunction do not do well when vision is removed (Black et al., 1983; Shumway-Cook & Horak, 1986). The increase in difficulty maintaining balance on a sponge surface compared to a fixed surface is consistent with other studies (Allum et al., 2002; Blackburn, 2003; Desai et al., 2010; Gill et al., 2001; Melzer, Benjuya, & Kaplanski, 2004).

Rine et al., (2013) in another study, developed a balance assessment using an accelerometer. There were 101 people in their study age 18 to 85, 18 of whom had vestibular pathology. The ICC values for eyes closed on a fixed surface were .83 and for eyes open on a sponge surface were .74. In the present study, ICC scores for eyes closed on the fixed surface were lower than in the Rine (2013) study however the ICC score was excellent when the eyes were open on the foam surface. The lower ICC scores with eyes closed may reflect the fact that the majority of the people in the Rine et al. study did not have vestibular dysfunction. The ICC scores for eyes closed on the fixed surface were lower than in the Rine (2013) study but are still considered good. People with vestibular pathology had excellent ICC scores for COP with eyes open and head still on the sponge surface similar to other studies done in sitting but their ICC scores decreased when vision was removed or head rotation was introduced.

The Rine (2013) study on balance correlated the accelerometer measurements with COP measurements taken from a force plate with a sponge placed on top of it. Problems associated with measuring COP with a sponge on top of the force plate have been well described by Betker et al., (2005) and Desai et al. (2010). They found that when the COP measurements were recorded from below the sponge rather from on top of the sponge as was done in the present study using the FSA mat, there was a decrease in the accuracy of COP from the dispersion of ground reaction forces through the sponge. The method of measuring COP that was used in the present study, where the FSA mat was placed on top of the sponge prior to the dispersion of forces, may have resulted in different scores.

The present study demonstrated that as the balance task became more difficult and the support surface more challenging, the ICC scores decreased. This is consistent with Pang, Lam, Wong, Au, & Chow (2011) who showed that as the visual and physical loads increased, ICC values decreased. They demonstrated excellent test retest reliability for the head shake SOT in healthy adults less than 50 years of age with ICC score of .82 on the firm surface and .78 on the sway referenced surface. Adults 50 years and older had ICC scores of .64 and .55 for the same tests.

In summary, the present study demonstrated how the new dynamic assessment tool is able to assess with moderate to excellent reliability the COD and the COP of people with vestibular hypofunction except for OL conditions on the sponge and treadmill. It extended the scope of the cDVA assessment beyond that of sitting on a chair and focusing on a stationary target during head movement by adding the very functional task of walking while simultaneously following a moving target. It also reliably assessed COP, which is a measure of balance, under varying physical and visual conditions, not just during quiet stance. Thus the first hypothesis which states that "computerized measures of dynamic balance and gaze control will demonstrate test-retest reliability in people with peripheral vestibular hypofunction" will fail to be rejected except for the condition of open loop walking.

7.3 Convergent Validity:

No clinically useful correlations were found between the DHI, the DVA and the DGI or between the DHI and how the subjects ranked their own symptoms with all correlations being below .35. This is consistent with the findings of Robertson and Ireland (1995) who found no useful clinical correlation between the DHI and Computerized Dynamic Posturography.

The DHI is a perception of one's dizziness does not reflect actual impairment. People that have had vestibular dysfunction for a long time may have maladapted and developed poor coping strategies in dealing with their symptoms. Yardley, Verschuur, Luxon, & Haake (1992) found no relationship between positive vestibular testing and actual diagnosis, symptoms, functional limitations and anxiety. They found that disability was affected by physical and psychological factors of which the autonomic symptoms played a role. Anxiety and fear of more vertigo attacks contributed to the perception of handicap indirectly. Robertson and Ireland (1995) felt that the discrepancy between computerized posturography and the DHI might be due to factors unrelated to the vestibular dysfunction itself but rather to the psychological impact of the disease process. It is possible that the reason the DHI does not correlate to tests of physical performance as it is a subjective questionnaire and does not objectively measure performance. It is therefore important as clinicians to limit reliance on patient's reports of dizziness given that there is no correlation with objective performance measures. It does however reflect a person’s responsiveness to change on testing (Tamber, Wilhelmsen, & Strand, 2009).

Low correlations were found between the clinical DVA test and COP and COD. The DVA test measures visual acuity in sitting with a stationary target while the head moves predictably in a side to side manner. None of the tests in the new assessment protocol were done in sitting with a stationary target so this might be the reason why it did not correlate well. While the computerized DVA is considered by many to be a reliable and valid measure of visual performance (Rine et al., 2013), it’s scope is limited in that it does not measure visual performance during functional tasks like walking or while looking at naturally moving objects in the environment. The new assessment tool can incorporate assessment of both visual acuity and balance while tracking moving objects when the head is stationary, when it moves predictably, and during unpredictable movements that occur during walking or on a sponge.

Low correlations were found between the DGI and COP in standing or COD in walking with the exception of a low correlation between the DGI and OL while walking on the treadmill. The DGI and the OL treadmill test had some similar balance and gaze requirements including walking over and around obstacles, walking with horizontal and vertical head rotations and turning which may may have accounted for the low correlation. It does not, however, quantify visual performance during testing. Furthermore it is known to have a low ceiling for younger, more mobile patients and does not measure those people with fewer impairments who function at a higher level of balance (Pardasaney et al., 2011).. Many of the study subjects were younger, with a mean age of 47.7 ±9.8 years of age and so the DGI may not have reflected their true ability due to ceiling effects.

Based on the above information, the second hypothesis which states that "computerized measures of dynamic balance and gaze control will demonstrate convergent reliability between the new assessment tool and the DVA, DGI and the DHI in people with peripheral vestibular hypofunction" will be rejected.

7.4 Construct Validity:

Altering the physical load, that is, the surface conditions and physical task did not change the COD of the visual tracking task significantly while sitting or standing on a fixed or foam surface. There was however, a significantly large decrease in COD during OL and CL treadmill walking. The decrease in COD at the treadmill level was observed at the same time that a large increase in passive head motion was observed. There was a 2 to 4 times increase in peak to peak linear head movement going from sitting to treadmill walking in some conditions coinciding with a large increase of amount of passive head movement in the ML direction.

These findings are consistent with the study by Lambert, Sigrist, Delaspre, Pelizzone, & Guyot (2010) and Hillman et al. (1999) which showed that the visual acuity of people with vestibular hypofunction decreased significantly while reading and walking on a treadmill compared to sitting or standing. Healthy people had much less difficulty with this task. When compared to normals, patients performance was significantly worse in standing and walking (p=.0001).

In the present study, there was a statistically significant decrease in the COD noted on the treadmill that was not present on the fixed surface or sponge. Previous studies examining the cDVA test have not challenged the physical load during visual acuity testing. Most cDVA testing has been done in sitting where there was no increase to the balance cost and where little passive or unpredictable head movement occurs. In this way, the new dynamic balance assessment tool can better emulate the conditions necessary for evaluating gaze control and visual acuity as experienced by people while walking and participating functionally in real life situations.

Yu, Yank, Villard, & Stoffregen (2010) studied sailors at sea and found that passive head movements and unpredictable motion resulting from rough seas decreased their visual and balance performance and increased COP variability. Consistent with this, the present study demonstrated large increases in passive and unpredictable head movements while walking coinciding with a simultaneous decrease in COD and gaze performance similar to the Yu et al. (2010) study. Most studies using cDVA have been done in sitting with very little cost to balance. The passive head movements observed while walking in the present study may have emulated the passive head movements experienced during rough seas that contributed to decreased balance and visual tracking performance.

Gaze stability is a challenge for people with vestibular dysfunction as they function and interact within a continuously changing environment. It can be difficult to maintain visual acuity of a moving object during movement of body and head through space and can vary depending upon the complexity of the activity. For example, it is easier to stabilize gaze during quiet stance if the object is stationary. This becomes more difficult if the person and the object are moving. As well, maintaining visual fixation on the fovea of the retina is easier with predictable movements than during unpredictable movements.

In the present study, when head rotation was combined with walking, large amounts of unpredictable movement were observed and visual tracking performance declined significantly. The smooth pursuit system and VOR act together to maintain the image of a moving target on the fovea of the retina while the head is rotating (Meyer et al., 1985). In people with deficient vestibular systems and reduced VOR, this becomes very difficult. Decreased VOR function secondary to vestibular loss results in retinal image slip during movement of the head causing an array of distressing symptoms including dizziness, visual blurring and loss of balance. Passive movements increased the head velocities possibly exceeding the limits where smooth pursuit was able to maintain foveal fixation resulting in retinal image slip and decreased tracking performance. Smooth pursuit typically functions at velocities of <100°/sec. and frequencies of < 1 Hz. and although the present study was able to control for head velocity and frequency below <100°/sec by using the predetermined frequency and amplitude of the computer-generated cursor the increase in passive movements while walking may have been too great. The increases in unpredictable head movement and the changes to visual tracking performance seen in walking may explain why clients with vestibular dysfunction have so much difficulty performing normal activities of daily living.

Different suggestions have been put forward as what compensatory strategies are used by people with vestibular hypofunction to deal with retinal image slip during head motion. Bockisch, Straumann, Hess, & Haslwanter (2004) suggested that an enhanced smooth pursuit may compensate for a deficient VOR. Schubert et al (2008) reported the use of compensatory saccades in dealing with retinal image slip during head motion. Visual acuity has been shown to improve with vestibular rehabilitation. Previous studies (Herdman, Hall, Schubert, Das, & Tusa, 2007; Schubert et al., 2008; Szturm et al., 1994) have shown that the aVOR can adapt to decreased gain through appropriate exercises and that vestibular rehabilitation can assist with recovery of aVOR and gaze stability in a population of people with vestibular hypofunction. Physiotherapy has a large role to play in this.

COP increased as the surface conditions changed from a fixed surface to a sponge surface. Group means and standard deviations for all conditions increased as the physical load went up. On the fixed surface, altering the visual load (eyes open and closed, OL and CL) did not have a statistically significant effect on COP total path length. Standing on a fixed surface with eyes open or closed as in the Romberg test is often too easy to challenge the vestibular system. A fixed surface is less likely to cause a balance disturbance because somatosensory information is available and is there is enough input from the peripheral nervous system to help with maintenance of balance even with the eyes closed (Menz et al., 2006). This becomes much more difficult on a sponge surface where the support surface is unpredictable (Betker et al., 2005; Desai et al., 2010; Fujimoto et al., 2012; Shumway-Cook & Horak, 1986; Strang et al., 2011).

When the visual loads were increased on the sponge during rotation of the head, COP sway path length increased substantially and significantly. This is consistent with previous studies demonstrating that when the head was rotated on a sponge surface or on a sway referenced surface, COP excursion increased significantly as compared to a fixed surface. Desai (2010), Honaker, Converse, & Shepard (2009) and Pang et al. (2011) all demonstrated a decrease in balance when standing on a sponge surface or sway referenced platform of the SOT. In the present study, the stimulation of the vestibular system through head rotation while on a sponge resulted in a further destabilization of balance.

Previous studies have looked at visual acuity of a stationary target in sitting where balance costs are low (Herdman, S; Tusa, R; Blatt, P; Suzuki, A; Venuto, P; Roberts, 1998; Mohammad et al., 2011; Rosemarie Rine et al., 2012). The present study took the basic components of the cDVA and extended the scope of these. It examined visual acuity while actively following a moving target versus a stationary target, not only in sitting but also in standing and walking where balance costs are higher and recorded visual acuity of a moving target quickly and easily.

Rine et al. (2013) examined changes to balance while standing on a foam similar to the mCTSIB by using an accelerometer attached to the pelvis. The present study took this a step farther to include walking while simultaneously measuring visual performance. It demonstrated that when the balance costs increased in walking versus quiet standing on a fixed or foam surface, there was a significant decrease in visual acuity in people with vestibular hypofunction. This is consistent with other studies (Hillman et al., 1999;

Lambert et al., 2010). The present study was able to incorporate both the visual tracking component of visual acuity assessment plus the walking component of balance assessment into one simple, quick and easy test. This new assessment tool is unique and improved over the other methods in that it broadens the range of testing previously reported by others and assesses balance and visual acuity under more conditions and levels of difficulty. By using a computer, assessments can be objective, quantified and standardized. This information can be incorporated into purposeful and appropriate exercise programs for people with vestibular dysfunction and can easily incorporate both unpredictable and predictable movements into balance and gaze tasks into a very functionally based treatment program capable of objectively monitoring changes for multiple patient groups.

The third hypothesis states that “computerized measures of dynamic balance and gaze control will demonstrate construct validity in people with peripheral vestibular hypofunction in situations where: 1. increases to physical load will cause a decrease in visual tracking performance and 2. increases in visual tracking demands will cause a decrease in visual tracking performance and a decrease in postural stability.” The study was able to demonstrate that this indeed does happen and hence we fail to reject the null hypothesis.

Strengths and Limitations:

This study evaluated how physical loads and visual conditions influenced each other in maintaining balance and gaze control. It combined two important clinical assessment tools (the DGI and DVA) and brought them together into one objective, quantifiable and reproducible test that can be done in the clinic. It demonstrated test-retest reliability for indexing balance and visual tracking performance in most conditions and extended the scope and evaluation capabilities of the NIH toolkit for vestibular function which uses the computerized DVA and the Balance Accelerometry Measure (Rine et al., 2013). The test protocols are functionally-based and quick and easy to perform. The gaze tracking component could be set up at home for approximately $100.00.

Secondly, this assessment tool evaluated vestibular and visual interaction of people while engaging in function. Previous visual acuity tests have been done in sitting and did not look at the effects of physical load on visual load. From this study we know that the challenge to gaze stability increases significantly while walking. This new assessment tool is able to evaluate this and is modifiable according to the patient's level of disability. The patient evaluation is computerized and objective, changes in performance can be measured over time.

One limitation of this test is that the software for quick analysis of balance performance and visual tracking which would make it readily accessible to the clinician has yet to be developed. Development of an affordable software package that can do the gaze tracking analysis instantaneously for improved feedback to the patient and timely adjustments to their exercise program is presently being investigated for commercial use.

Another limitation of this study is that many of the clients could not complete the tests. The present study recruited 30 people with vestibular hypofunction. A limitation of this study is the reduced power due to the number of people recruited for the study.

Further study with larger numbers would allow a greater pool of data and greater power. Evaluating unilateral and bilateral clients separately might be helpful in narrowing down the specific needs of each subgroup group of patients. Recruiting a large sample of appropriate vestibular clients that meet the inclusion and exclusion criteria is difficult in smaller regions.

Physical support surfaces and visual tasks interact with each other to influence stability and visual tracking performance. Increasing the demands of the visual tasks did not affect stability measures (COP) while standing on the fixed surfaces in our population of vestibular clients but did when standing on the sponge. Another effect was seen between the physical demands and the visual tracking performance as measured by the COD. Visual tracking performance declined significantly on the treadmill with both open and closed loop conditions.

Knowing how balance and vision affect each other functionally can be used clinically useful in teaching patients with vestibular hypofunction how to improve their visual tracking and assist with maintaining the image on the fovea of the retina during function. Training a person with vestibular dysfunction to foveate on a moving target is an important part of a vestibular treatment. Vestibular stressing exercises requiring foveation on a moving target while balancing on a sponge or while walking should be incorporated into treatment programs. Objective assessments can provide valuable information to the therapist to aid in the design of appropriate exercise programs for their clients

The development of the new assessment tool is ongoing. It. It can assess people with vestibular dysfunction as well as other diagnostic categories such as strokes, traumatic brain injuries or amputees.   The new tool can objectively quantify visual performance in gait.   Further development has potential to provide gait parameters such as step width and length variability, double support time, and other gait variables useful in predicting fall risk. The new tool is useful not just for assessment purposes, but also as a training tool. The visual tracking tasks and gait speed can be modified depending on age and level of ability allowing for objective measurement of performance and timely feedback useful in training. This is presently being studied. The DHI, which measures a person's perception of their handicap, did not correlate to objective measures of balance and dizziness. This leads one to be cautious about relying on subjective reports of symptoms.

Clinical significance:

Clinical tests of balance and visual performance such as the DGI and the DVA provide valuable information about vestibular functioning. They have been shown to be reliable but are limited in scope and are subject to misinterpretation by the evaluator. There are ceiling effects among certain populations and minor changes in performance may not be easily identified. The new assessment tool described in this paper is capable of objectively capturing this information with one standardized test. The COD test can be extended for use with clients who are unable to attend clinic for treatment but who can send their performance data to the therapist to be analyzed through electronic means via the logged data file. This allows the therapist to provide timely feedback to the client and modification to their home program. Since this assessment is electronically based, monitoring of COD and compliance with home programs can be done using the internet which has positive implications for people in rural areas. It can also be used to provide third party payers with a wealth of objective information about changes in function.

The scope of the testing using the dynamic balance assessment is broad and can be adapted to a variety of real life situations that include but are not limited to standing, walking and tracking visual targets for any target population. This study has provided valuable information about balance and visual performance in a population of people with vestibular deficits. Computer-generated assessments and indexing of visual and balance function provides reliable and objective that can measure change over time. Future consideration for studies include the ongoing development of this test includes analysis of gait variables while performing visual tracking and cognitive tasks, testing the effect of passive head movement on visual acuity and balance, testing vertical head movements, telerehabilitation feasibility studies, and study of multiple age groups which will further aid in treatment approaches for those with balance and mobility issues in a wide range of clients.

Chapter 8: References

Adsuar, J. C., Olivares, P. R., Parraca, J. a, Hernández-Mocholí, M. a, & Gusi, N. (2012). Applicability and Test-Retest Reliability of Isokinetic Shoulder Abduction and Adduction in Women Fibromyalgia Patients. *Archives of physical medicine and rehabilitation*, 444–450. doi:10.1016/j.apmr.2012.08.198

Aiken, F., & Murnane, O. (2007). Vestibular Evoked Myogenic Potentials. In Garry Jacobson & N. Shepard (Eds.), *Balance Function Assessment and Management* (pp. 405–434). San Diego: Plural Publishing Inc. Retrieved from http://www.amazon.com/Balance-Function-Assessment-Management-Gary/dp/1597561002

Allum, J. H. J., Zamani, F., Adkin, a L., & Ernst, a. (2002). Differences between trunk sway characteristics on a foam support surface and on the Equitest ankle-sway-referenced support surface. *Gait & posture*, *16*(3), 264–70. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12443951

Alsalaheen, B. a, Mucha, A., Morris, L. O., Whitney, S. L., Furman, J. M., Camiolo-Reddy, C. E., … Sparto, P. J. (2010). Vestibular rehabilitation for dizziness and balance disorders after concussion. *Journal of neurologic physical therapy : JNPT*, *34*(2), 87–93. doi:10.1097/NPT.0b013e3181dde568

Angelaki, D. E. (2004). Eyes on target: what neurons must do for the vestibuloocular reflex during linear motion. *Journal of neurophysiology*, *92*(1), 20–35. doi:10.1152/jn.00047.2004

Angelaki, D. E., Zhou, H.-H., & Wei, M. (2003). Foveal versus full-field visual stabilization strategies for translational and rotational head movements. *The Journal of neuroscience : the official journal of the Society for Neuroscience*, *23*(4), 1104–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12598596

Arriaga, M. a, Chen, D. a, & Cenci, K. a. (2005). Rotational chair (ROTO) instead of electronystagmography (ENG) as the primary vestibular test. *Otolaryngology--head and neck surgery : official journal of American Academy of Otolaryngology-Head and Neck Surgery*, *133*(3), 329–33. doi:10.1016/j.otohns.2005.05.002

Asmundson, G., Stein, M., & Ireland, D. (1999). Original contribution A factor analytic study of the dizziness handicap inventory : does it assess phobic avoidance in vestibular referrals ? *Journal of Vestibular Research*, *9*, 63–68.

Atkinson, G., & Nevill, A. M. (1998). Measurement Error (Reliability) in Variables Relevant to Sports Medicine. *Sport Med*, *26*(4), 217–238.

Balatsouras, D. G., Ganelis, P., Aspris, A., Economou, N. C., Moukos, A., & Koukoutsis, G. (2012). Benign Paroxysmal Positional Vertigo Associated With Meniere ' s Disease : Epidemiological , Pathophysiologic , Clinical , and Therapeutic Aspects. *The Annals of otology, rhinology & laryngology*, *121*(10), 682–688.

Baloh, R. W. (1998, December 5). Vertigo. *Lancet*. doi:10.1016/S0140-6736(98)05430-0

Baloh, R. W. (2003). Vestibular Neuronitis. *N Engl J Med*, *384*, 1027–32.

Barber, H. (1984). Vestibular Neurophysiology. *Otolaryngology - head and neck surgery [0194-5998]*, *92*, 55–58.

Barin, K. (2008). Background and Technique of Caloric Testing. In Gary Jacobson & N. Shepard (Eds.), *Balnce Function Assessment and Management* (pp. 197–252). San Diego: Plural Publishing.

Berg, K., Wood-Dauphinee, S., Williams, J., & Maki, B. (1992). Measuring balance in the elderly: validation of an instrument. *Canadian Journal of Public Health*, *83*(Suppl 2), s7–11.

Betker, A, Szturm, T., & Moussavi, Z. (2005). Development of an interactive motivating tool for rehabilitation movements. *Conference proceedings : ... Annual International*

Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference, *3*, 2341–4. doi:10.1109/IEMBS.2005.1616935

Betker, A. L., Moussavi, Z. M. K., & Szturm, T. (2005). On modeling center of foot pressure distortion through a medium. *IEEE transactions on bio-medical engineering*, *52*(3), 345–52. doi:10.1109/TBME.2004.840466

Betker, AL, Szturm, T., & Moussavi, Z. (2009). Estimation of 2-D Center of Mass Movement During Trunk Flexion–Extension Movements Using Body Accelerations Betker 2009. *IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING,*, *16*(6), 553–559. doi:10.1109/TNSRE.2009.2032620

Black, F., Wall, C., & Nashner, L. M. (1983). Effects of visual and support surface orientation references upon postural control in vestibular deficient subjects. *Acta oto-laryngologica*, *95*(3-4), 199–201. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6601353

Blackburn, J. (2003). Kinematic analysis of the hip and trunk during bilateral stance on firm, foam, and multiaxial support surfaces. *Clinical Biomechanics*, *18*(7), 655–661. doi:10.1016/S0268-0033(03)00091-3

Bockisch, C. J., Straumann, D., Hess, K., & Haslwanter, T. (2004). Enhanced smooth pursuit eye movements in patients with bilateral vestibular deficits. *Neuroreport*, *15*(17), 2617–20. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15570163

Bogle Thorbahn, L. D., & Newton, R. a. (1996). Use of the Berg Balance Test to predict falls in elderly persons. *Physical therapy*, *76*(6), 576–83; discussion 584–5. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8650273

Borel, L., Lopez, C., Péruch, P., & Lacour, M. (2008). Vestibular syndrome: a change in internal spatial representation. *Neurophysiologie clinique = Clinical neurophysiology*, *38*(6), 375–89. doi:10.1016/j.neucli.2008.09.002

Brey, R., McPherson, J., & Lynch, R. (2007). Background and Introduction to Whole Body Rotational Testing. In Gary Jacobson & N. Shepard (Eds.), *Balance Function Assessment and Management* (pp. 253–280). San Diego: Plural Publishing.

Bronstein, A. (1995). Visual vertigo syndrome: clinical and posturography findings. *Journal of Neurology, Neurosurgery & Psychiatry*, *59*, 472–476. Retrieved from http://jnnp.bmj.com/content/59/5/472.short

Centers for Disease Control and Prevention. (2011). Concussion and Mild TBI. *Injury Prevention and Control: Traumatic Brain Injury*. Retrieved March 29, 2012, from http://www.cdc.gov/concussion/

Chen, Y., Huang, W.-G., Zha, D.-J., Qiu, J.-H., Wang, J.-L., Sha, S.-H., & Schacht, J. (2007). Aspirin attenuates gentamicin ototoxicity: from the laboratory to the clinic. *Hearing research*, *226*(1-2), 178–82. doi:10.1016/j.heares.2006.05.008

Cinelli, M., Patla, A., & Stuart, B. (2008). Age-related differences during a gaze reorientation task while standing or walking on a treadmill. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, *185*(1), 157–64. doi:10.1007/s00221-007-1266-8

Cohen, H., Blatchly, C. a, & Gombash, L. L. (1993). A study of the clinical test of sensory interaction and balance. *Physical therapy*, *73*(6), 346–51; discussion 351–4. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8497509

Cohen, H., & Kimball, K. (2008). Usefulness of some current balance tests for identifying individuals with disequilibrium due to vestibular impairments. *Journal of Vestibular Research*, 295–303.

Cox, K., Lee, D., Carey, J., & Minor, L. (2003). Dehiscence of bone overlying the superior semicircular canal as a cause of an air-bone gap on audiometry a case study Minor 2003.pdf. *Am J of Audiology*, *12*, 11–16.

Creath, Rob, Kiemel, T., Horak, F., & Jeka, J. J. (2002). Limited control strategies with the loss of vestibular function. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, *145*(3), 323–33. doi:10.1007/s00221-002-1110-0

Creath, Robert, Kiemel, T., Horak, F., Peterka, R., & Jeka, J. (2005). A unified view of quiet and perturbed stance: simultaneous co-existing excitable modes. *Neuroscience letters*, *377*(2), 75–80. doi:10.1016/j.neulet.2004.11.071

Cremer, P. D., Halmagyi, G. M., Aw, S. T., Curthoys, I. S., McGarvie, L. a, Todd, M. J., … Hannigan, I. P. (1998). Semicircular canal plane head impulses detect absent function of individual semicircular canals. *Brain : a journal of neurology*, *121 (Pt 4*, 699–716. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9577395

Dannenbaum, E., Paquet, N., Chilingaryan, G., & Fung, J. (2009). Clinical evaluation of dynamic visual acuity in subjects with unilateral vestibular hypofunction. *Otology & neurotology : official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *30*(3), 368–72. doi:10.1097/MAO.0b013e31819bda35

Dannenbaum, Elizabeth; Hakim-Zadeh, Roghieh; Paquet, Nicole; Feldman, A. (2005). Optimal Parameters for the Clinical Test of Dynamic Visual Acuity in Patients with a Unilateral Vestibular Deficit. *The Journal of Otolaryngology.*, *34*(01), 13–19.

Demer, J. L., & Viirre, E. S. (1996). Visual-vestibular interaction during standing, walking, and running. *Journal of vestibular research : equilibrium & orientation*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8839825

Demer Joseph; Honrubia Vicente; Baloh Robert. (1994). Dynamic Visual Acuity: A test for oscillopsia and Vestibulo-ocular function Demer 1994.pdf. *The American Journal of Otology*, *15*(3), 340–347.

Desai, A., Szturm, T., Betker, A., & Goodman, V. (2010). Relationship between Dynamic Balance Measures and Functions Performance in Community Dwelling Seniors. *Physical Therapy*, *90*(5), 748–760. doi:DOI: 10.2522/ptj.20090100

Diehl, M. D., & Pidcoe, P. E. (2010). The influence of gaze stabilization and fixation on stepping reactions in younger and older adults. *Journal of geriatric physical therapy (2001)*, *33*(1), 19–25. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20503730

Dietz, V., Trippel, M., Ibrahim, I. K., & Berger, W. (1993). Balance control by feedforward and feedback mechanisms. *Experimental Brain Research*, 352–362.

Dulon, D., Hiel, H., Aurousseau, C., Erre, J., & Aran, J. (1993). Pharmacokinetics of gentamicin in the sensory hair cells of the organ of Corti: rapid uptake and long term persistence. *Comptes Rendus de L'Academie des Sciences—Serie III, Sciences de la Vie*, *316*, 682–687.

Duracinsky, M., Mosnier, I., Bouccara, D., Sterkers, O., & Chassany, O. (2007). Literature review of questionnaires assessing vertigo and dizziness, and their impact on patients' quality of life. *Value in health : the journal of the International Society for Pharmacoeconomics and Outcomes Research*, *10*(4), 273–84. doi:10.1111/j.1524-4733.2007.00182.x

Duysens, J., Duysens, J. P., Bastiaanse, C. M., van Sprundel, M., Schubert, M., & Smits-Engelsman, B. C. M. (2008). How trunk turns affect locomotion when you are not looking where you go. *Human movement science*, *27*(5), 759–70. doi:10.1016/j.humov.2008.04.004

Enloe, L. J., & Shields, R. K. (1997). Evaluation of health-related quality of life in individuals with vestibular disease using disease-specific and general outcome measures. *Physical therapy*, *77*(9), 890–903. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9291947

Enticott, J. C., O'leary, S. J., & Briggs, R. J. S. (2005). Effects of vestibulo-ocular reflex exercises on vestibular compensation after vestibular schwannoma surgery. *Otology & neurotology : official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *26*(2), 265–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15793417

Fetter, M. (2007). Vestibular System Disorders. In Susan Herdman (Ed.), *Vestibular Rehabilitation, 3rd Edition (Contemporary Perspectives in Rehabilitation)* (3rd ed., pp. 98–106). Phliadelphia: F.A. Davis Company. Retrieved from http://www.amazon.com/Vestibular-Rehabilitation-Edition-Contemporary-Perspectives/dp/0803613768

Fielder, H., Denholm, S. W., Lyons, R. a, & Fielder, C. P. (1996). Measurement of health status in patients with vertigo. *Clinical otolaryngology and allied sciences*, *21*(2), 124–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8735395

Finch, E., Brooks, D., Stratford, P., & Mayo, N. (2002). *Physical Rehabilitation Outcomes Measures: A Guide to Enhanced Clinical Decision-Making*. (E; Finch, D. Brooks, P. Startford, & N. Mayo, Eds.) (2nd ed., pp. 26–41). Hamilton, Ontario: BC Decker Inc. for Canadian Physiotherapy Association.

Friedland, D. R., & Wackym, P. A. (1999). A critical appraisal of spontaneous perilymphatic fistulas of the inner ear Friedland. *The American Journal of Otology*, *20*(2), 261–279.

Fujimoto, C., Murofushi, T., Sugasawa, K., Chihara, Y., Ushio, M., Yamasoba, T., & Iwasaki, S. (2012). Assessment of postural stability using foam posturography at the chronic stage after acute unilateral peripheral vestibular dysfunction. *Otology &*

neurotology : official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, *33*(3), 432–6. doi:10.1097/MAO.0b013e3182487f48

Ghez, C. (1991). Posture. In E. R. Kandel, J. Schwartz, & Jessel' Thomas (Eds.), *Principles of Neural Science* (3rd ed., pp. 596–607). New york: Elsevier,. Retrieved from http://lrpapp.cc.umanitoba.ca/uhtbin/cgisirsi/YkG3FOJ5dM/DAFOE/58500129/9

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. *The journals of gerontology. Series A, Biological sciences and medical sciences*, *56*(7), M438–47. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11445603

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. *Archives of physical medicine and rehabilitation*, *90*(8), 1325–31. doi:10.1016/j.apmr.2009.01.032

Goebel, J. (2001). The ten-minute examination of the dizzy patient. *Seminars in neurology*, *21*(4), 391–8. doi:10.1055/s-2001-19410

Goldberg, M., Eggers, H., & Gouras, P. (1991). The Ocular Motor System. In E. R. Kandel, J. Scwartz, & T. Jessel (Eds.), *Principles of Neural Science* (3rd ed., pp. 660–677). New York: Elsevier,. Retrieved from http://lrpapp.cc.umanitoba.ca/uhtbin/cgisirsi/qkzEtGLHCa/DAFOE/36580018/9

Gottshall, K., Topp, S., & Hoffer, M. (2010). Early vestibular physical therapy rehabilitation for Meniere's disease. *Otolaryngologic clinics of North America*, *43*(5), 1113–9. doi:10.1016/j.otc.2010.05.006

Hain, T., & Helminski, J. (2007). Anatomy and Physiology of the Normal Vestibular System. In Susan Herdman (Ed.), *Vestibular Rehabilitation* (3rd ed., pp. 1–18). Philadelphia: F.A. Davis,. Retrieved from http://lrpapp.cc.umanitoba.ca/uhtbin/cgisirsi/ww8gQu9FyN/DAFOE/147960016/9

Hall, C. D., & Herdman, S. J. (2006). Reliability of clinical measures used to assess patients with peripheral vestibular disorders. *Journal of neurologic physical therapy : JNPT*, *30*(2), 74–81. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16796772

Hall, C. D., Schubert, M. C., & Herdman, S. J. (2004). Prediction of fall risk reduction as measured by dynamic gait index in individuals with unilateral vestibular hypofunction. *Otology & neurotology : official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *25*(5), 746–51. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15354006

Halmagyi, M., & Curthoys, I. (2007). Otolith Function Tests. In Susan Herdman (Ed.), *Vestibular Rehabilitation(Contemporary Perspectives in Rehabilitation)* (3rd ed., pp. 144–161). Philadelphia: F.A. Davis Co.

Hassard, T. (1991). *Understanding Biostatistics* (pp. 52–74). St. Louis, issouri, USA: Mosby-Year Book.

Herdman, S, Clendaniel, R., Mattox, D., Holliday, M., & Niparko, J. (1995). Vestibular adaptation exercises and recovery: Acute stage after acoustic neuroma resection. *Otolaryngology - Head and Neck Surgery*, *113*(1), 77–87. doi:10.1016/S0194-5998(95)70148-6

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. *Archives of otolaryngology--head & neck surgery*, *133*(4), 383–9. doi:10.1001/archotol.133.4.383

Herdman, S. J., Schubert, M. C., Das, V. E., & Tusa, R. J. (2003). Recovery of dynamic visual acuity in unilateral vestibular hypofunction. *Archives of otolaryngology--head & neck surgery*, *129*(8), 819–24. doi:10.1001/archotol.129.8.819

Herdman, S; Tusa, R; Blatt, P; Suzuki, A; Venuto, P; Roberts, D. (1998). Computerized dynamic visual acuity test in the Assessment of Vestibular Deficits Herdman 1998.pdf. *The American Journal of Otology*, *19*, 790–796.

Hillman, E. J., Bloomberg, J. J., McDonald, P. V, & Cohen, H. S. (1999). Dynamic visual acuity while walking in normals and labyrinthine-deficient patients. *Journal of vestibular research : equilibrium & orientation*, *9*(1), 49–57. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10334016

Honaker, J. a, Converse, C. M., & Shepard, N. T. (2009). Modified head shake computerized dynamic posturography. *American journal of audiology*, *18*(2), 108–13. doi:10.1044/1059-0889(2009/09-0012)

Honaker, J. a, & Shepard, N. T. (2011). Use of the Dynamic Visual Acuity Test as a screener for community-dwelling older adults who fall. *Journal of vestibular research : equilibrium & orientation*, *21*(5), 267–76. doi:10.3233/VES-2011-0427

Horak, F. B., Shupert, C. L., Dietz, V., & Horstmann, G. (1994). Vestibular and somatosensory contributions to responses to head and body displacements in stance. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, *100*(1), 93–106. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7813657

Horak, F., Nashner, L., & Diener, H. (1990). Postural Strategies associatedwith somatosensory and vestibular loss. *Experimental Brain Research*, *82*, 167–177.

Ishiyama, G. (2009). Imbalance and Vertigo : The Aging Human Vestibular Periphery. *Seminars in Neurology*, *29*, 491–499. doi:10.1055/s-0029-1241039.

Jacobson, G, Newman, C., Hunter, L., & Gene, B. (1991). Balance Function Test Correlates of the DHI Jacobson 1991.pdf. *J Am Acad Audiol, 2*, 253–260.

Jacobson, G. P., & Newman, C. W. (1990). The development of the Dizziness Handicap Inventory. *Archives of otolaryngology--head & neck surgery, 116*(4), 424–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2317323

Kaiser, P. K. (2009). Prospective evaluation of visual acuity assessment: a comparison of snellen versus ETDRS charts in clinical practice (An AOS Thesis). *Transactions of the American Ophthalmological Society, 107*, 311–24. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2814576&tool=pmcentrez&rendertype=abstract

Kammerlind, A., Bergquist Larsson, P., Ledin, T., & Skargren, E. (2005). Reliability of clinical balance tests and subjective ratings in dizziness and disequilibrium. *Advances in Physiotherapy, 7*(3), 96–107. doi:10.1080/14038190510010403

Kammerlind, A., Håkansson, J. K., & Skogsberg, M. C. (2001). Effects of balance training in elderly people with nonperipheral vertigo and unsteadiness. *Clinical Rehabilitation, 15*(5), 463–470. doi:10.1191/026921501680425180

Kandel, E., Schwartz, J. H., & Jessel, T. (Eds.). (1991). *Principles of neural science* (3rd ed.). New York: Elsevier,. Retrieved from http://lrpapp.cc.umanitoba.ca/uhtbin/cgisirsi/Gxsmk4KvxB/ELECTRONIC/53050024/9

Karatas, M. (2008). Central vertigo and dizziness: epidemiology, differential diagnosis, and common causes. *The neurologist, 14*(6), 355–64. doi:10.1097/NRL.0b013e31817533a3

Kayan, A., & Hood, J. (1984). Neuro-otological Manifestations of Migraine. *Brain, 107*, 1123–1142.

Kelly, J. (1991). The Sense of Balance. In Eric Kandel, J. Schwartz, & T. Jessel (Eds.), *Principles of neural science* (3rd ed., pp. 500–511). New York: Elsevier,. Retrieved from http://lrpapp.cc.umanitoba.ca/uhtbin/cgisirsi/G1Ty3ErpsM/DAFOE/159130114/9

Kim, H., So, H., Lee, J., Park, C., Youn, M., Kim, S., … Park, R. (2008). ORIGINAL ARTICLE ROLE OF PROINFLAMMATORY CYTOKINES IN CISPLATIN-INDUCED VESTIBULAR HAIR CELL DAMAGE. *In Vivo*, (November), 1445–1456. doi:10.1002/hed

Kroenke, K., Stump, T., Clark, D., Callahan, C., & McDonald, C. (2011). Symptoms in Hospitalized Patients: Outcome and Satisfaction with Care. *Otolaryngology--head and neck surgery : official journal of American Academy of Otolaryngology-Head and Neck Surgery*, *145*(1), 110–6. doi:10.1177/0194599811400007

Lacour, M., Dutheil, S., Tighilet, B., Lopez, C., & Borel, L. (2009). Tell me your vestibular deficit, and i’ll tell you how you'll compensate. *Annals of the New York Academy of Sciences*, *1164*, 268–78. doi:10.1111/j.1749-6632.2008.03731.x

Lafond, D., Corriveau, H., Hebert, R., & Prince, F. (2004). Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people1. *Archives of Physical Medicine and Rehabilitation*, *85*(6), 896–901. doi:10.1016/j.apmr.2003.08.089

Lambert, S., Sigrist, A., Delaspre, O., Pelizzone, M., & Guyot, J.-P. (2010). Measurement of dynamic visual acuity in patients with vestibular areflexia. *Acta oto-laryngologica*, *130*(7), 820–3. doi:10.3109/00016480903426592

Land, M. F. (2006). Eye movements and the control of actions in everyday life. *Progress in retinal and eye research*, *25*(3), 296–324. doi:10.1016/j.preteyeres.2006.01.002

LaPlante, J., & Kaeser, T. (2007). 3 rd Urban Street Symposium A HISTORY OF PEDESTRIAN SIGNAL WALKING SPEED ASSUMPTIONS, 1–8.

Leigh, R. J., & Zee, D. (1999). *The Neurology of Eye Movements* (Third., pp. 19–89). New York: Oxford University Press.

Lexall, J., & Downham, D. (2005). How to Assess the Reliability of Measurements in Rehabilitation. *Am J Phys Med Rehabil ;84:, 84*, 719–723.

Liao, K., Walker, M. F., Joshi, A., Reschke, M., & Leigh, R. J. (2008). Vestibulo-ocular responses to vertical translation in normal human subjects. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, *185*(4), 553–62. doi:10.1007/s00221-007-1181-z

Loader, B., Gruther, W., Mueller, C. a, Neuwirth, G., Thurner, S., Ehrenberger, K., & Mittermaier, C. (2007). Improved postural control after computerized optokinetic therapy based on stochastic visual stimulation in patients with vestibular dysfunction. *Journal of vestibular research : equilibrium & orientation*, *17*(2-3), 131–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18413906

Longridge, NS; Mallinson, A. (1984). A discussion of the dynamic illegible “E” test: a new method of screening for aminoglycoside vestibulotoxicity. *Otolaryngology - head and neck surgery [0194-5998]*, *92*(6), 671–677.

Longridge, NS; Mallinson, A. (1987). The dynamic illegible E (DIE) test: a simple technique for assessing the ability of the vestibulo-ocular reflex to overcome vestibular pathology. *The Journal of Otolaryngology [0381-6605]*, *16*(2), 97–103.

Lord, S. R., & Menz, H. B. (2000). Visual contributions to postural stability in older adults. *Gerontology*, *46*(6), 306–10. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11044784

Loughran, S., Gatehouse, S., Kishore, A., & Swan, I. R. C. (2006). Does patient-perceived handicap correspond to the modified clinical test for the sensory interaction on balance? *Otology & neurotology : official publication of the American Otological Society, American Neurotology Society [and] European Academy of*

Otology and Neurotology, *27*(1), 86–91. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16371852

Maki, B. E., & McIlroy, W. E. (1996). Postural control in the older adult. *Clin Geriatr Med.*, *12*(4), 635–658.

Mandalà, M., & Nuti, D. (2009). Long-term follow-up of vestibular neuritis. *Annals of the New York Academy of Sciences*, *1164*, 427–9. doi:10.1111/j.1749-6632.2008.03721.x

Marchetti, G. F., Whitney, S. L., Blatt, P. J., Morris, L. O., & Vance, J. M. (2008). Temporal and Spatial Characteristics of Gait During Performance of the Dynamic Gait Index in People With and People Without Balance or Vestibular Disorders. *Physical Therapy*, *88*(5), 640–651.

Maskell, F., Chiarelli, P., & Isles, R. (2006). Dizziness after traumatic brain injury: overview and measurement in the clinical setting. *Brain injury : [BI]*, *20*(3), 293–305. doi:10.1080/02699050500488041

Melzer, I., Benjuya, N., & Kaplanski, J. (2004). Postural stability in the elderly: a comparison between fallers and non-fallers. *Age and ageing*, *33*(6), 602–7. doi:10.1093/ageing/afh218

Menz, H. B., Lord, S. R., & Fitzpatrick, R. C. (2006). A tactile stimulus applied to the leg improves postural stability in young, old and neuropathic subjects. *Neuroscience letters*, *406*(1-2), 23–6. doi:10.1016/j.neulet.2006.07.014

Merchant, S. N., Adams, J. C., & Nadol, J. B. (2005). Pathophysiology of Meniere's syndrome: are symptoms caused by endolymphatic hydrops? *Otology & neurotology : official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *26*(1), 74–81. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15699723

Meyer, C. H., Lasker, A. G., & Robinson, D. a. (1985). THE UPPER LIMIT OF HUMAN. *Vision Research*, *25*(4), 561–563.

Minor, L. B. (2005). Clinical manifestations of superior semicircular canal dehiscence. *The Laryngoscope*, *115*(10), 1717–27. doi:10.1097/01.mlg.0000178324.55729.b7

Mohammad, M. T., Whitney, S. L., Marchetti, G. F., Sparto, P. J., Ward, B. K., & Furman, J. M. (2011). The reliability and response stability of dynamic testing of the vestibulo-ocular reflex in patients with vestibular disease. *Journal of vestibular research : equilibrium & orientation*, *21*(5), 277–88. doi:10.3233/VES-2011-0430

Mohammad, M. T., Whitney, S. L., Sparto, P. J., Jennings, J. R., & Furman, J. M. (2010). Perceptual and motor inhibition in individuals with vestibular disorders. *Journal of neurologic physical therapy : JNPT*, *34*(2), 76–81. doi:10.1097/NPT.0b013e3181dde582

Mulavara, A. P., & Bloomberg, J. J. (2003). Identifying head-trunk and lower limb contributions to gaze stabilization during locomotion. *Journal of vestibular research : equilibrium & orientation*, *12*(5-6), 255–69. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14501102

Ohyama, S., Nishiike, S., Watanabe, H., Matsuoka, K., & Takeda, N. (2008). Effects of optokinetic stimulation induced by virtual reality on locomotion: a preliminary study. *Acta oto-laryngologica*, *128*(11), 1211–4. doi:10.1080/00016480801901683

Orban de Xivry, J.-J., & Lefèvre, P. (2007). Saccades and pursuit: two outcomes of a single sensorimotor process. *The Journal of physiology*, *584*(Pt 1), 11–23. doi:10.1113/jphysiol.2007.139881

Pang, M. Y. C., Lam, F. M., Wong, G. H., Au, I. H., & Chow, D. L. (2011). Balance performance in head-shake computerized dynamic posturography: aging effects and test-retest reliability. *Physical therapy*, *91*(2), 246–53. doi:10.2522/ptj.20100221

Pardasaney, P. K., Latham, N. K., Jette, A. M., Wagenaar, R. C., Ni, P., Slavin, M. D., & Bean, J. F. (2011). Sensitivity to Change and Responsiveness of Four Balance Measures for Community-Dwelling Older Adults. *Physical therapy*. doi:10.2522/ptj.20100398

Patel, M., Fransson, P. a, Lush, D., Petersen, H., Magnusson, M., Johansson, R., & Gomez, S. (2008). The effects of foam surface properties on standing body movement. *Acta oto-laryngologica*, *44*(October 2007), 1–9. doi:10.1080/00016480701827517

Pérez-Garrigues, H., Kuessner, D., & Benecke, H. (2007). Patient baseline characteristics in an open-label multinational study of betahistine in recurrent peripheral vestibular vertigo: the OSVaLD study. *Current medical research and opinion*, *23*(11), 2753–61. doi:10.1185/03007X233016

Peterka, R. (2002). Sensorimotor Integration in Human Postural Control Peterka 2002. *J Neurophysiol*, *88*, 1097–1118.

Pothula, V. B., Chew, F., Lesser, T. H. J., & Sharma, a K. (2004). Falls and vestibular impairment. *Clinical otolaryngology and allied sciences*, *29*(2), 179–82. doi:10.1111/j.0307-7772.2004.00785.x

Redfern, M. S., Yardley, L., & Bronstein, a M. (2001). Visual influences on balance. *Journal of anxiety disorders*, *15*(1-2), 81–94. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11388359

Reiter, R. J., Tan, D., & Korkmaz, A. (2011). Review article Aminoglycoside (AG) AG-Fe Apoptosis Cyt c DNA. *Journal of Pineal Research*, 151–157.

Riddle, D., & Stratford, P. (2013). *Is this change real? Interpreting Patient outcomes in Physical Therapy*. Philadelphia: FA Davis Co.

Rine, RM, 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

Rine, Rosemarie, Roberts, D., Corbin, B. A., Mckean-cowdin, R., Varma, R., Beaumont, J., … Schubert, M. C. (2012). Institutes of Health Toolbox initiative. *J Rehabil Res Dev.*, *49*(2), 209–220.

Rosenhall, U. (1973). DEGENERATIVE PATTERNS IN THE AGING HUMAN vestibular neuro-epithelium, *73*(1-6), 208–220.

Rybak, L. P., & Ramkumar, V. (2007). Ototoxicity. *Kidney international*, *72*(8), 931–5. doi:10.1038/sj.ki.5002434

Salehi, R., Ebrahimi-takamjani, I., Esteki, A., & Maroufi, N. (2010). Test-retest reliability and minimal detectable change for center of pressure measures of postural stability in elderly subjects, *23*(4), 224–232.

Scherer, M., Migliaccio, A. a, & Schubert, M. C. (2008). Effect of vestibular rehabilitation on passive dynamic visual acuity. *Journal of vestibular research : equilibrium & orientation*, *18*(2-3), 147–57. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2952034&tool=pmcentrez&rendertype=abstract

Schubert, M., Bohner, C., Berger, W., Sprundel, M. V, & Duysens, J. E. J. (2003). The role of vision in maintaining heading direction: effects of changing gaze and optic flow on human gait. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, *150*(2), 163–73. doi:10.1007/s00221-003-1390-z

Schubert, M. C., Migliaccio, A. a, Clendaniel, R. a, Allak, A., & Carey, J. P. (2008). Mechanism of dynamic visual acuity recovery with vestibular rehabilitation. *Archives of physical medicine and rehabilitation*, *89*(3), 500–7. doi:10.1016/j.apmr.2007.11.010

Schubert, M. C., & Minor, L. B. (2004). Vestibulo-ocular physiology underlying vestibular hypofunction. *Physical therapy*, *84*(4), 373–85. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15049730

Schubert, M. C., Tusa, R. J., Grine, L. E., & Herdman, S. J. (2004). Optimizing the Sensitivity of the Head Thrust Test for Identifying. *Physical Therapy*, *84*, 151–158.

Schubert, M., Tusa, R., Grine, L., & Herdman, S. (2004). Optimizing the sensitivity of the head thrust test for identifying vestibular hypofunction. *Physical therapy*, *84*(2), 151–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14744205

Shrout, P., & Fleiss, J. (1979). Intraclass Correlations: Uses in Assessing Rater Relability. *Psychological Bulletin*, *86*(2), 420–428.

Shumway-Cook, a, Baldwin, M., Polissar, N. L., & Gruber, W. (1997). Predicting the probability for falls in community-dwelling older adults. *Physical therapy*, *77*(8), 812–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10960937

Shumway-Cook, A., Gruber, W., Baldwin, M., & Liao, S. (1997). The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults. *Physical therapy*, *77*(1), 46–57. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8996463

Shumway-Cook, A., & Horak, F. (1986). Assessing the influence of sensory interaction of balance. Suggestion from the field. *Physical therapy*, *66*(10), 1548–50. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3763708

Sloane, P. D., Coeytaux, R. R., Beck, R. S., & Dallara, J. (2001). Dizziness : State of the Science. *Annals of Internal Medicine*, *134*(9_Part_2), 823–832.

Smart, L. J., Stoffregen, T. a., & Bardy, B. G. (2002). Visually Induced Motion Sickness Predicted by Postural Instability. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *44*(3), 451–465. doi:10.1518/0018720024497745

Staab, J. P., & Ruckenstein, M. J. (2005). Chronic dizziness and anxiety: effect of course of illness on treatment outcome. *Archives of otolaryngology--head & neck surgery*, *131*(8), 675–9. doi:10.1001/archotol.131.8.675

Strang, A. J., Haworth, J., Hieronymus, M., Walsh, M., & Smart, L. J. (2011). Structural changes in postural sway lend insight into effects of balance training, vision, and support surface on postural control in a healthy population. *European journal of applied physiology*, *111*(7), 1485–95. doi:10.1007/s00421-010-1770-6

Stratford, P., & Spadoni, G. (2003). Sample size estimation for the comparison of competing Measures reliability coefficients Stratford Spadoni 2003.pdf. *Physiotherapy Canada*, *55*, 225–229.

Streiner, D. L., & Norman, G. R. (2008). Health Measurement Scales: A practical guide to their development and use. In *Health Measurement Scales: A practical guide to their development and use* (pp. 167–210; 247–276). Hamilton, Ontario: Oxford University Press. doi:10.1093/acprof:oso/9780199231881.001.0001

Szturm, T., Betker, A., Moussavi, Z., Desai, A., & Goodman, V. (2011). Effects of an interactive computer game exercise regimen on balance impairment in frail community-dwelling older adults: a randomized controlled trial. *Physical therapy*, *91*(10), 1449–62. doi:10.2522/ptj.20090205

Szturm, T., Ireland, D., & Lessing-Turner, M. (1994). Comparison of different exercise programs in the rehabilitation of patients with chronic peripheral vestibular dysfunction. *Journal of vestibular research : equilibrium & orientation*, *4*(6), 461–479.

Szturm, T., Peters, J., Otto, C., Kapadia, N., & Desai, A. (2008). Task-specific rehabilitation of finger-hand function using interactive computer gaming. *Archives of physical medicine and rehabilitation*, *89*(11), 2213–7. doi:10.1016/j.apmr.2008.04.021

Tamber, A.-L., Wilhelmsen, K. T., & Strand, L. I. (2009). Measurement properties of the Dizziness Handicap Inventory by cross-sectional and longitudinal designs. *Health and quality of life outcomes*, *7*, 101. doi:10.1186/1477-7525-7-101

Teasdale, N., Stelmach, G. E., & Breunig, a. (1991). Postural sway characteristics of the elderly under normal and altered visual and support surface conditions. *Journal of gerontology*, *46*(6), B238–44. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1940075

Tinetti, M. E., & Williams, C. S. (1998). The effect of falls and fall injuries on functioning in community-dwelling older persons. *The journals of gerontology. Series A, Biological sciences and medical sciences*, *53*(2), M112–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9520917

Tinetti, M. E., Williams, C. S., & Gill, T. M. (2000). Dizziness among older adults: a possible geriatric syndrome. *Annals of internal medicine*, *132*(5), 337–44. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10691583

Tusa, R. (2007). Vestibular Function Tests. In Susan Herdman (Ed.), *Vestibular Rehabilitation, 3rd Edition (Contemporary Perspectives in Rehabilitation)* (3rd ed., pp. 125–143). Philadelphia: F.A. Davis Co.

Van Asten, W. N., Gielen, C. C., & van der Gon, J. J. (1988). Postural movements induced by rotations of visual scenes. *Journal of the Optical Society of America. A, Optics and image science*, *5*(10), 1781–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3204442

Van Ooteghem, Karen; Frank, James; Horak, F. (2010). NIH Public Access. *Brain*. doi:10.1007/s00221-009-1995-y.Practice-related

Venuto, P., Herdman, S., Tusa, R., Erb, D., Yang, S., & Blatt, P. (1998). Interrater reliability of the Clinical Dynamic Visual Acuity test. *Physical Therapy*, *78*(5), S21.

Vereeck, L., Truijen, S., Wuyts, F. L., & Van De Heyning, P. H. (2007). Internal consistency and factor analysis of the Dutch version of the Dizziness Handicap Inventory. *Acta oto-laryngologica*, *127*(8), 788–95. doi:10.1080/00016480601075464

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

Vitte, E., Sémont, a, & Berthoz, a. (1994). Repeated optokinetic stimulation in conditions of active standing facilitates recovery from vestibular deficits. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, *102*(1), 141–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7895790

Wang, C. Y., Sheu, C. F., & Protas, E. J. (2009). Test-retest reliability and measurement errors of six mobility tests in the community-dwelling elderly, *4*(1), 8–13.

Wei, M., & Angelaki, D. E. (2004). Does head rotation contribute to gaze stability during passive translations? *Journal of neurophysiology*, *91*(4), 1913–8. doi:10.1152/jn.01044.2003

Whipple, R., Wolfson, L., Derby, C., Singh, D., & Tobin, J. (1993). Altered sensory function and balance in older persons. *Journal of gerontology, 48 Spec No*(8), 71–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8409244

Whitney, S, Hudak, M., & Marchetti, G. (2000). The Dynamic Gait Index relates to self-reported fall history in individuals with vestibular dysfunction. *J Vestib Res., 10*(2), 99–105.

Whitney, S, Marchetti, G., Schade, A., & Wrisley, D. (2004). The sensitivity and specificity of the Timed “Up & Go” and the Dynamic Gait Index for self-reported falls in persons with vestibular disorders. *Journal of vestibular research :*

equilibrium & orientation, *14*(5), 397–409. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15598995

Whitney, S, Wrisley, D., Brown, K., & Furman, J. (2000). Physical Therapy for Migraine-Related Vestibulopathy and Vestibular Dysfunction With History of Migraine Study Design : Retrospective case series Methods : *Physical Therapy*, (September), 1528–1534.

Whitney, S, Wrisley, D., & Furman, J. (2003). Concurrent validity of the Berg Balance Scale and the Dynamic Gait Index in people with vestibular dysfunction. *Physiotherapy research international : the journal for researchers and clinicians in physical therapy*, *8*(4), 178–86. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14730722

Whitney, S. L., Hudak, M. T., & Marchetti, G. F. (2000). The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction. *Journal of vestibular research : equilibrium & orientation*, *10*(2), 99–105. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10939685

Whitney, SL, Roche, J., Marchetti, G., Lin, C., Steed, D., Furman, G., … Redfern, M. (2011). A comparison of accelerometry and center of pressure measures during computerized dynamic posturography: A measure of balance. *Gait & Posture*, *33*, 594–599.

Wier, J. (2005). Quantifying Test-Retest Reliability Using the Intraclass Correlation Coefficient and the SEM. *Journal of Strength and Conditioning Research*, *19*(1), 231–240.

Wilhelmsen, K., Strand, L. I., Nordahl, S. H. G., Eide, G. E., & Ljunggren, A. E. (2008). Psychometric properties of the Vertigo symptom scale - Short form. *BMC ear, nose, and throat disorders*, *8*, 2. doi:10.1186/1472-6815-8-2

World Health Organization. (2002). Towards a Common Language for Functioning , Disability and Health ICF. *International Classification*, *1149*(2), 1–4. Retrieved from http://www.who.int/classifications/icf/training/icfbeginnersguide.pdf

Wrisley, D. M., Marchetti, G. F., Kuharsky, D. K., & Whitney, S. L. (2004). Reliability, internal consistency, and validity of data obtained with the functional gait assessment. *Physical therapy*, *84*(10), 906–18. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15449976

Yamasoba, T., Lin, F. R., Someya, S., Kashio, A., Sakamoto, T., & Kondo, K. (2013). Current concepts in age-related hearing loss: Epidemiology and mechanistic pathways. *Hearing research*, 1–9. doi:10.1016/j.heares.2013.01.021

Yardley, L., Verschuur, C., Luxon, L., & Haake, N. (1992). Somatic and psychological factors contributing to handicap in people with vertigo. *Br J Audiology*, *26*(5), 283–290.

Ying-Ta Lai, Ting-Chuan Wang, Li-Ju Chuang, M.-H. C. and P.-C. W. (2011). Epidemiology of Vertigo : A National Survey. *Otolaryngology -- Head and Neck Surgery*, *145*(March). doi:DOI: 10.1177/0194599811400007

Yu, Y., Yank, J. R., Villard, S., & Stoffregen, T. A. (2010). Postural activity and visual vigilance performance during rough seas. *Aviation, space, and environmental medicine*, *81*(9), 843–849. doi:10.3357/ASEM.2768.2010

Zupan, L. H., Peterka, R. J., Merfeld, D. M., Macneilage, P. R., Turner, A. H., Angelaki, D. E., … Wood, S. (2000). Neural Processing of Gravito-Inertial Cues in Humans . I . Influence of the Semicircular Canals Following Post-Rotatory Tilt Neural Processing of Gravito-Inertial Cues in Humans . I . Influence of the Semicircular Canals Following Post-Rotatory Tilt. *Journal of Neurophysiology*, 2001–2015.

Chapter 9: Appendix

Appendix A:

Dynamic Gait Index

Grading: Mark the lowest category which applies. Total individual scores (24 possible). Scores of 19 or less have been related to increase incidence of falls in the elderly.

1. Gait Level Surface ______
Instructions: Walk at your normal speed from here to the next mark (20').
Grading: Mark the lowest category that applies.

(3) Normal: Walks 20', no assistive devices, good speed, no evidence for imbalance, normal gait pattern.
(2) Mild impairment: Walks 20', uses assistive devices, slower speed, mild gait deviations.
(1) Moderate impairment: Walks 20', slow speed, abnormal gait pattern, evidence for imbalance.
(0) Severe impairment: Cannot walk 20' without assistance, severe gait deviations, or imbalance.

2. Change in gait speed ______
Instructions: Begin walking at your normal pace (for 5'), when I tell you "go," walk as fast as you can (for 5'). When I tell you "slow," walk as slowly as you can (for 5').

(3) Normal: Able to smoothly change walking speed without loss of balance or gait deviation. Shows a significant difference in walking speeds between normal, fast, and slow speeds.
(2) Mild impairment: Able to change speed but demonstrates mild gait deviations, or no gait deviations but unable to achieve a significant change in velocity, or uses and assistive device.
(1) Moderate impairment: Makes only minor adjustments to walking speed, or accomplishes a change in speed with significant gait deviations, or changes speed but has significant gait deviations, or changes speed but loses balance but is able to recover and continue walking.
(0) Severe impairment: Cannot change speeds, or loses balance and has to reach for wall or be caught.

3. Gait with horizontal head turns ______
Instructions: Begin walking at your normal pace. When I tell you to "look right," keep walking straight, but turn your head to the right. Keep looking to the right until I tell you "look left," then keep walking straight and turn your head to the left. Keep your head to the left until I tell you, "look straight," then keep walking straight but return your head to the center.

(3) Normal: Performs head turns smoothly with no change in gait.
(2) Mild impairment: Performs head turns smoothly with slight change in gait velocity (i.e., minor disruption to smooth gait path or uses walking aid).

(1) Moderate impairment: Performs head turns with moderate change in gait velocity, slows down, staggers but recovers, can continue to walk.
(0) Severe impairment: Performs task with severe disruptions of gait (i.e., staggers outside 15º path, loses balance, stops, reaches for wall).

4. Gait with vertical head turns ______
Instructions: Begin walking at your normal pace. When I tell you to "look up," keep walking straight, but tip your head and look up. Keep looking up until I tell you "look down," then keep walking straight and turn your head down. Keep looking down until I tell you, "look straight," then keep walking straight but return your head to the center.
(3) Normal: Performs head turns with no change in gait.
(2) Mild impairment: Performs task with slight change in gait velocity (i.e., minor disruption to smooth gait path or uses walking aid).
(1) Moderate impairment: Performs tasks with moderate change in gait velocity, slows down, staggers but recovers, can continue to walk.
(0) Severe impairment: Performs task with severe disruption or gait (i.e., staggers outside 15º path, loses balance, stops reaches for wall).

5. Gait and pivot turn ______
Instructions: Begin walking at your normal pace. When I tell you to "stop and turn," turn as quickly as you can to face the opposite direction and stop.

(3) Normal: Pivot and turns safely within 3 seconds and stops quickly with no loss of balance.
(2) Mild impairment: Pivot turns safely in >3 seconds and stops with no loss of balance.
(1) Moderate impairment: Turns slowly, requires verbal cueing, requires several small steps to catch balance following turn and stop.
(0) Severe impairment: Cannot turn safely, requires assistance to turn and stop.

6. **Step over obstacle** ______
   Instructions: Begin walking at your normal speed. When you come to the shoe box, step over it, not around it, and keep walking.

(3) Normal: Able to step over box without changing gait speed; no evidence for imbalance.
(2) Mild impairment: Able to step over box, but must slow down and adjust steps to clear box safely.
(1) Moderate impairment: Able to step over box but must stop, then step over. May require verbal cueing.
(0) Severe impairment: Cannot perform without assistance.

7. Step around obstacles ______
Instructions: Begin walking at your normal speed. When you come to the first cone (about 6' away), walk around the right side of it. When you come to the second cone (6' past first cone), walk around it to the left.

(3) Normal: Able to walk around cones safely without changing gait speed; no evidence of imbalance.
(2) Mild impairment: Able to step around both cones, but must slow down and adjust steps to clear cones.
(1) Moderate impairment: Able to clear cones but must significantly slow speed to accomplish task, or requires verbal cueing.
(0) Severe impairment: Unable to clear cones, walks into one or both cones, or requires physical assistance.

8. Stairs ______
Instructions: Walk up these stairs as you would at home (i.e., using the rail if necessary). At the top, turn around and walk down.
(3) Normal: Alternating feet, no rail.
(2) Mild impairment: Alternating feet, must use rail.
(1) Moderate impairment: Two feet to stair, must use rail.
(0) Severe impairment: Cannot perform safely.

(Adapted from Shumway-Cook A, Wollacott M. Motor Control: Theory and Practical Applications. Baltimore: Williams and Wilkins, 1995).
AROM.COM – The web address for Physical Therapy

Appendix B:

Dizziness Handicap Inventory

INSTRUCTIONS: The purpose of this questionnaire is to identify difficulties that you may be experiencing because of your dizziness. Please answer every question. Please do not skip any questions.

1. Does looking up increase your problem?
   Yes Sometimes No

2. Because of your problem, do you feel frustrated?
   Yes Sometimes No

3. Because of your problem, do you restrict your travel for business or recreation?
   Yes Sometimes No

4. Does walking down the aisle of a supermarket increase your problem?
   Yes Sometimes No

5. Because of your problem, do you have difficulty getting into or out of bed?
   Yes Sometimes No

6. Does your problem significantly restrict your participation in social activities such as going out to dinner, going to movies, dancing, or to parties?
   Yes Sometimes No

7. Because of your problem, do you have difficulty reading?
   Yes Sometimes No

8. Does performing more ambitious activities like sports, dancing, household chores such as sweeping or putting dishes away increase your problem?
   Yes Sometimes No

9. Because of your problem, are you afraid to leave home without having someone with you?
   Yes Sometimes No

10. Because of your problem, have you been embarrassed in front of others?
    Yes Sometimes No

11. Do quick movements of your head increase your problem?
    Yes Sometimes No

12. Because of your problem, do you avoid heights?
    Yes Sometimes No

13. Does turning over in bed increase your problem?

Yes Sometimes No

14. Because of your problem, is it difficult for you to do strenuous housework yardwork?

Yes Sometimes No

15. Because of your problem, are you afraid people may think you are intoxicated?

Yes Sometimes No

16. Because of your problem, is it difficult for you to go for a walk by yourself?

Yes Sometimes No

17. Does walking down a sidewalk increase your problem?

Yes Sometimes No

18. Because of your problem, is it difficult for you to concentrate?

Yes Sometimes No

19. Because of your problem, is it difficult for you to go for a walk around your house in the dark?

Yes Sometimes No

20. Because of your problem, are you afraid to stay home alone?

Yes Sometimes No

21. Because of your problem, do you feel handicapped?

Yes Sometimes No

22. Has your problem placed stress on your relationship with members of your family or friends?

Yes Sometimes No

23. Because of your problem, are you depressed?

Yes Sometimes No

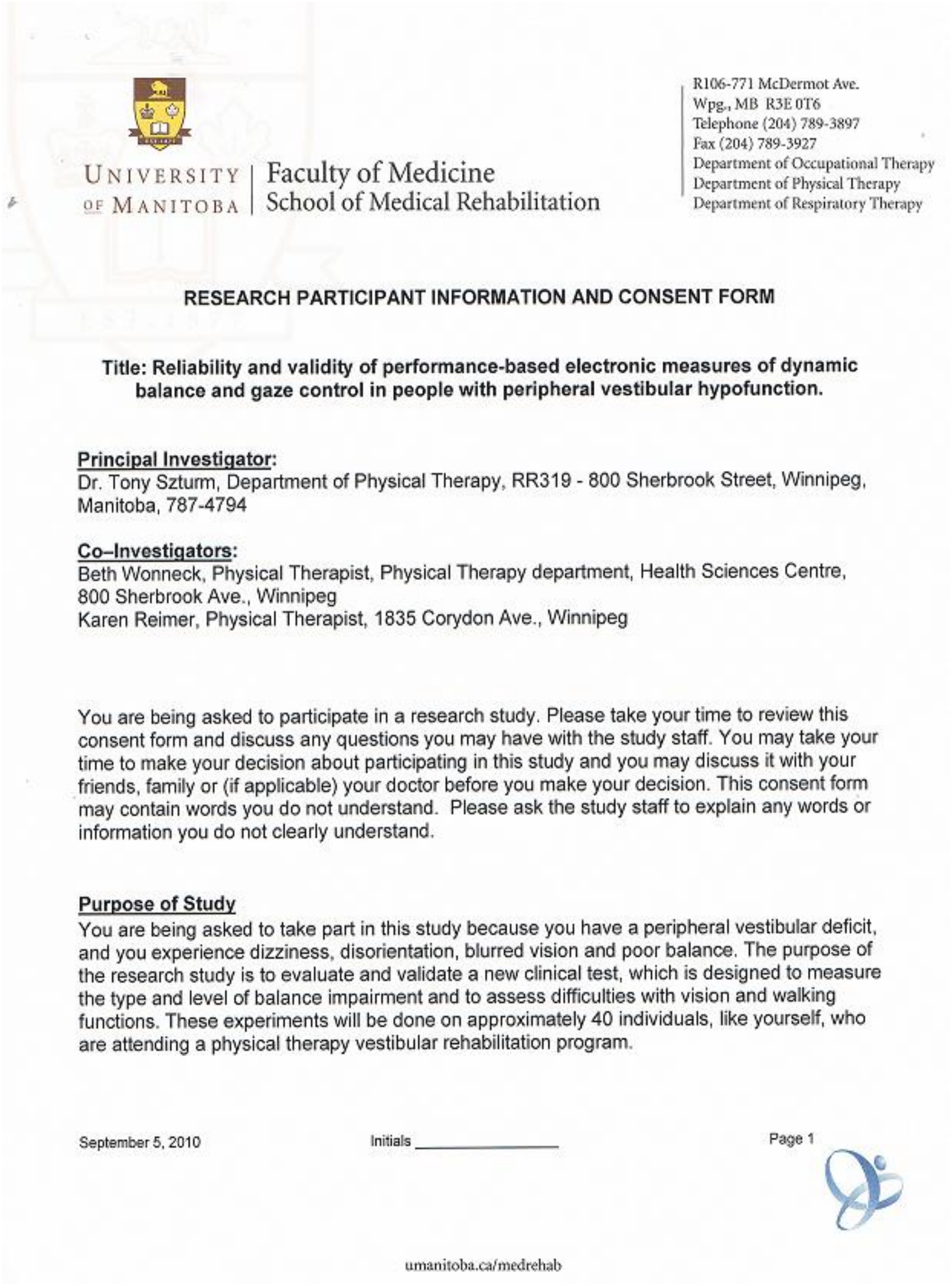
24. Does your problem interfere with your job or household responsibilities?

Yes Sometimes No

25. Does bending over increase your problem?

Yes Sometimes No

Appendix C: Consent form



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RESEARCH PARTICIPANT INFORMATION AND CONSENT FORM

Title: Reliability and validity of performance-based electronic measures of dynamic balance and gaze control in people with peripheral vestibular hypofunction.

Principal Investigator:
Dr. Tony Szturm, Department of Physical Therapy, RR319 - 800 Sherbrook Street, Winnipeg, Manitoba, 787-4794

Co–Investigators:
Beth Wonneck, Physical Therapist, Physical Therapy department, Health Sciences Centre, 800 Sherbrook Ave., Winnipeg
Karen Reimer, Physical Therapist, 1835 Corydon Ave., Winnipeg

You are being asked to participate in a research study. Please take your time to review this consent form and discuss any questions you may have with the study staff. You may take your time to make your decision about participating in this study and you may discuss it with your friends, family or (if applicable) your doctor before you make your decision. This consent form may contain words you do not understand. Please ask the study staff to explain any words or information you do not clearly understand.

Purpose of Study
You are being asked to take part in this study because you have a peripheral vestibular deficit, and you experience dizziness, disorientation, blurred vision and poor balance. The purpose of the research study is to evaluate and validate a new clinical test, which is designed to measure the type and level of balance impairment and to assess difficulties with vision and walking functions. These experiments will be done on approximately 40 individuals, like yourself, who are attending a physical therapy vestibular rehabilitation program.

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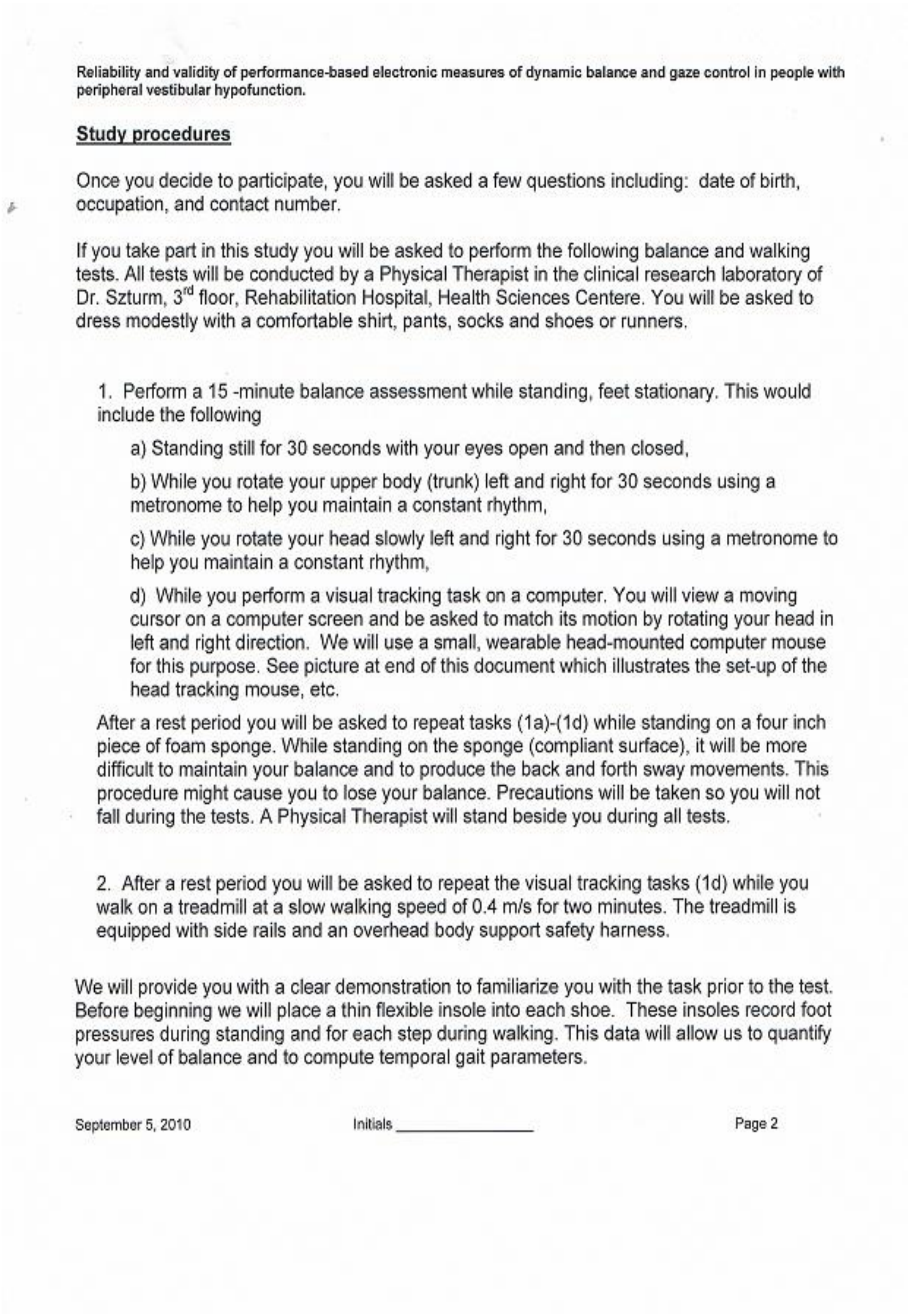
umanitoba.ca/medrehab



Study procedures

Once you decide to participate, you will be asked a few questions including: date of birth, occupation, and contact number.

If you take part in this study you will be asked to perform the following balance and walking tests. All tests will be conducted by a Physical Therapist in the clinical research laboratory of Dr. Szturm, 3rd floor, Rehabilitation Hospital, Health Sciences Centere. You will be asked to dress modestly with a comfortable shirt, pants, socks and shoes or runners.

1. Perform a 15 -minute balance assessment while standing, feet stationary. This would include the following

    a) Standing still for 30 seconds with your eyes open and then closed,

    b) While you rotate your upper body (trunk) left and right for 30 seconds using a metronome to help you maintain a constant rhythm,

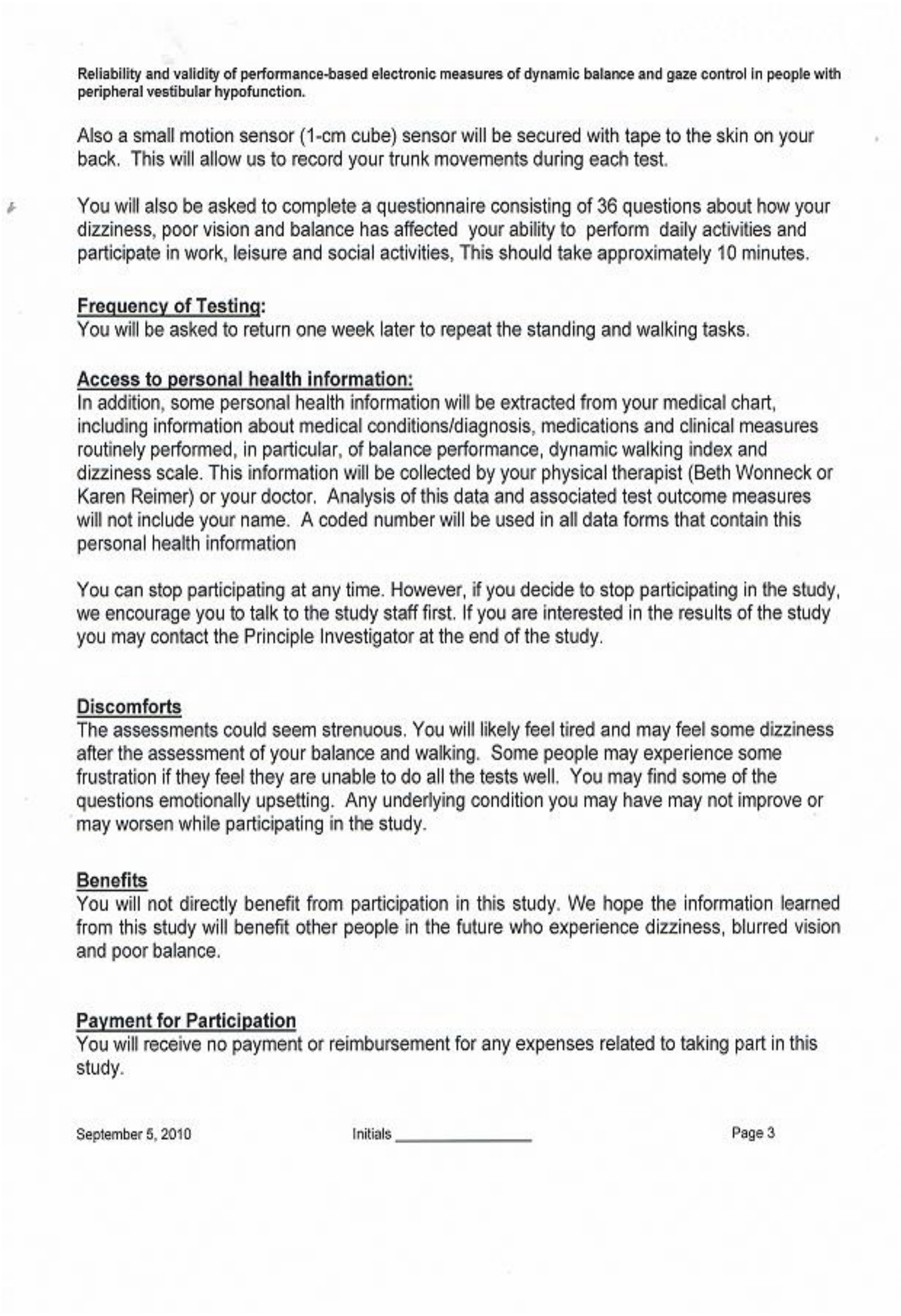
    c) While you rotate your head slowly left and right for 30 seconds using a metronome to help you maintain a constant rhythm,

    d) While you perform a visual tracking task on a computer. You will view a moving cursor on a computer screen and be asked to match its motion by rotating your head in left and right direction. We will use a small, wearable head-mounted computer mouse for this purpose. See picture at end of this document which illustrates the set-up of the head tracking mouse, etc.

    After a rest period you will be asked to repeat tasks (1a)-(1d) while standing on a four inch piece of foam sponge. While standing on the sponge (compliant surface), it will be more difficult to maintain your balance and to produce the back and forth sway movements. This procedure might cause you to lose your balance. Precautions will be taken so you will not fall during the tests. A Physical Therapist will stand beside you during all tests.

2. After a rest period you will be asked to repeat the visual tracking tasks (1d) while you walk on a treadmill at a slow walking speed of 0.4 m/s for two minutes. The treadmill is equipped with side rails and an overhead body support safety harness.

We will provide you with a clear demonstration to familiarize you with the task prior to the test. Before beginning we will place a thin flexible insole into each shoe. These insoles record foot pressures during standing and for each step during walking. This data will allow us to quantify your level of balance and to compute temporal gait parameters.



Also a small motion sensor (1-cm cube) sensor will be secured with tape to the skin on your back. This will allow us to record your trunk movements during each test.

You will also be asked to complete a questionnaire consisting of 36 questions about how your dizziness, poor vision and balance has affected your ability to perform daily activities and participate in work, leisure and social activities, This should take approximately 10 minutes.

Frequency of Testing:
You will be asked to return one week later to repeat the standing and walking tasks.

Access to personal health information:
In addition, some personal health information will be extracted from your medical chart, including information about medical conditions/diagnosis, medications and clinical measures routinely performed, in particular, of balance performance, dynamic walking index and dizziness scale. This information will be collected by your physical therapist (Beth Wonneck or Karen Reimer) or your doctor. Analysis of this data and associated test outcome measures will not include your name. A coded number will be used in all data forms that contain this personal health information

You can stop participating at any time. However, if you decide to stop participating in the study, we encourage you to talk to the study staff first. If you are interested in the results of the study you may contact the Principle Investigator at the end of the study.

Discomforts
The assessments could seem strenuous. You will likely feel tired and may feel some dizziness after the assessment of your balance and walking. Some people may experience some frustration if they feel they are unable to do all the tests well. You may find some of the questions emotionally upsetting. Any underlying condition you may have may not improve or may worsen while participating in the study.

Benefits
You will not directly benefit from participation in this study. We hope the information learned from this study will benefit other people in the future who experience dizziness, blurred vision and poor balance.

Payment for Participation
You will receive no payment or reimbursement for any expenses related to taking part in this study.

Confidentiality

Information gathered in this research study may be published or presented in public forums; however your name and other identifying information will not be used or revealed. Despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law. Medical records that contain your identity will be treated as confidential in accordance with the Personal Health Information Act of Manitoba.

The University of Manitoba Health Research Ethics Board may review records related to the study for quality assurance purposes.

No information revealing any personal information such as your name will leave the University of Manitoba.

Voluntary Participation/Withdrawal from the Study

Your decision to take part in this study is voluntary. You may refuse to participate or you may withdraw from the study at any time.

Participants who are students or employees of either The University of Manitoba or Health Sciences Centre or individuals associated professionally with any of the investigators can be assured that a decision not to participate will in no way affect any performance evaluation of potential participants.

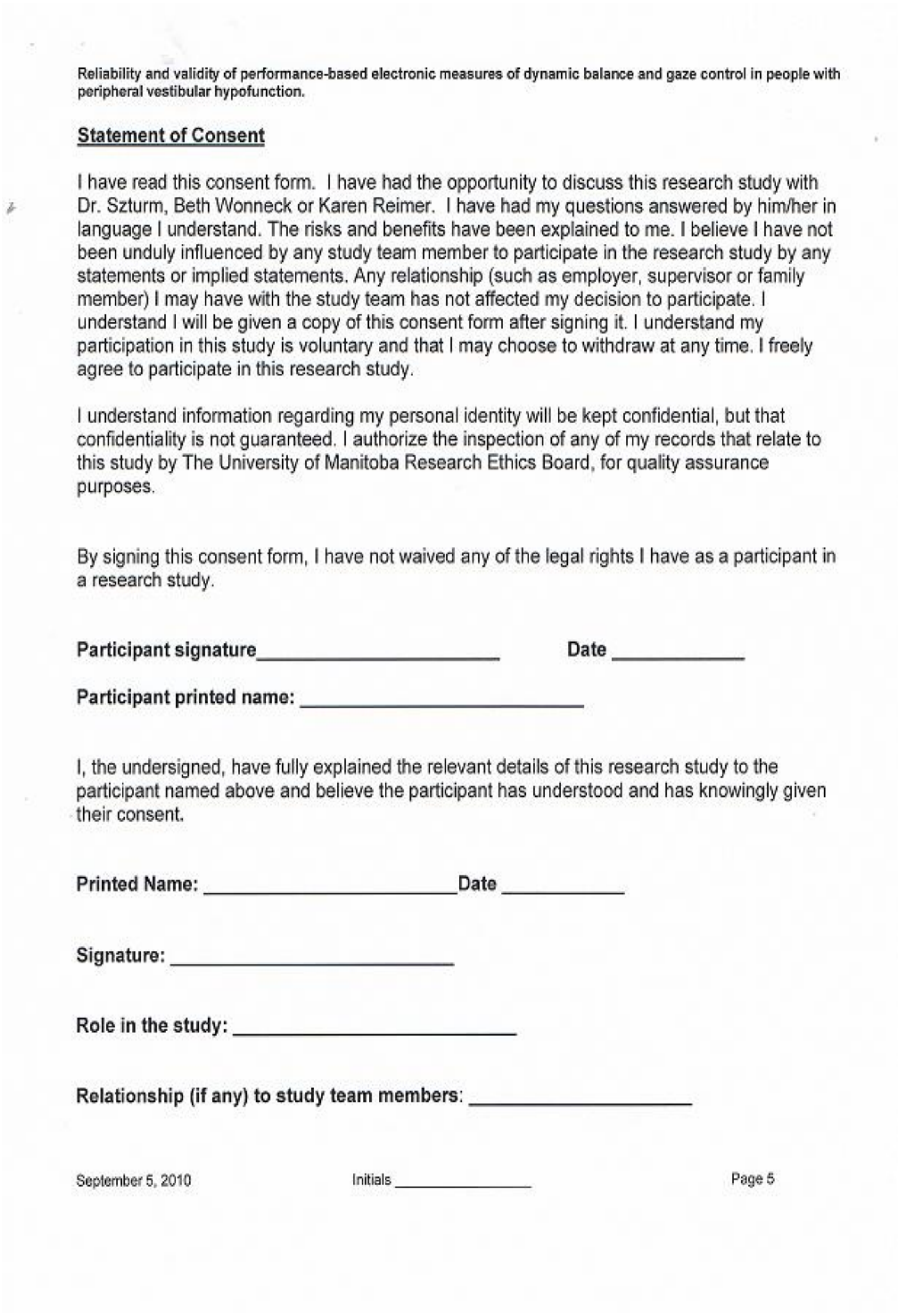
Medical Care for Injury Related to the Study

You are not waiving any of your legal rights by signing this consent form or releasing the investigator from their legal and professional responsibilities.

Questions

You are free to ask any questions you may have about your treatment and your rights as a research participant. If any questions come up during or after the study or if you have a research-related injury, contact any one of the study Co-investigators: Dr. Tony Szturm (204) 787-4794, Beth Wonneck (204) 787-2203 or Karen Reimer (204) 227-3002.

For questions about your rights as a research participant, you may contact The University of Manitoba, Bannatyne Campus Research Ethics Board Office at (204) 789-3389. Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.



Statement of Consent

I have read this consent form. I have had the opportunity to discuss this research study with Dr. Szturm, Beth Wonneck or Karen Reimer. I have had my questions answered by him/her in language I understand. The risks and benefits have been explained to me. I believe I have not been unduly influenced by any study team member to participate in the research study by any statements or implied statements. Any relationship (such as employer, supervisor or family member) I may have with the study team has not affected my decision to participate. I understand I will be given a copy of this consent form after signing it. I understand my participation in this study is voluntary and that I may choose to withdraw at any time. I freely agree to participate in this research study.

I understand information regarding my personal identity will be kept confidential, but that confidentiality is not guaranteed. I authorize the inspection of any of my records that relate to this study by The University of Manitoba Research Ethics Board, for quality assurance purposes.

By signing this consent form, I have not waived any of the legal rights I have as a participant in a research study.

Participant signature________________________ **Date** _____________

Participant printed name: ____________________________

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe the participant has understood and has knowingly given their consent.

Printed Name: _________________________**Date** ____________

Signature: ____________________________

Role in the study: ____________________________

Relationship (if any) to study team members: ______________________