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The effects of aging and unilateral vestibular disorders on the kinematic performance of vestibular rehabilitation exercises and physical function

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THE EFFECTS OF AGING AND UNILATERAL VESTIBULAR DISORDERS ON THE KINEMATIC PERFORMANCE OF VESTIBULAR REHABILITATION EXERCISES AND PHYSICAL FUNCTION

A Dissertation

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by
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NOMENCLATURE OF ABBREVIATED TERMS

ADL	Activities of Daily Living
CDP	Computerized Dynamic Posturography
CoM	Center of Mass
CNS	Central Nervous System
CS-PFP-10	Continuous Scale of Physical Functional Performance
CTSIB	Computerized Test of Sensory Integrated Balance
DHI	Dizziness Handicap Inventory
SHA	Sinusoidal Harmonic Acceleration
SOP	Sensory Organization Performance
SOT	Sensory Organization Test
SPV	Slow Phase Velocity
VADL	Vestibular Disorders Activities of Daily Living
VOR	Vestibulo-ocular Reflex
VR	Vestibular Rehabilitation

ABSTRACT

The overall purpose of this study was to evaluate the effects of unilateral vestibular disorders and aging on functional performances of activities of daily living and vestibular rehabilitation exercises by examining the correlations among actual and perceived functional measures, the kinematic measurement differences among young healthy adults, older healthy adults, and older adults with unilateral vestibular deficits, and the correlations between kinematic and functional measures. Perceived and actual functional abilities and kinematic variables were compared for young controls, older healthy controls, and patients with unilateral vestibular hypofunction with no previous vestibular rehabilitation. In older adults, better strength, balance, coordination, and endurance during activities of daily living were associated with better perceived ambulation and reduction in perceived functional handicap. Older adults had difficulties stabilizing their heads relative to the environment during eye exercises and moved their heads more when the exercise required head stabilization relative to the body, probably due to alterations in performance of the exercises. Patients, who were also older adults, were able to suppress some of these movements, likely to prevent dizziness. Both older groups often reduced their head movements and/or moved differently from the young when movements were self-selected and not externally driven by a visual cue. When patients were forced to make greater horizontal head movements with intermittent gaze stabilization, they also made greater head movements orthogonal to the plane of motion for seated exercises. These findings show that some patient differences are linked to declines of normal aging and not that of the disorder. In addition patients took more steps at a slower pace for the gait with head movement exercise. The group differences in exercise kinematics guided the correlations between kinematics and functional data, so that the subject differences in correlations between actual function and head excursion kinematics differed from those for perceived function and head excursion kinematics. These data add to the limited findings on associations between kinematic measurements and functional performances in vestibular patients and are the first to show relationships exist between these measures for healthy young adults, healthy older adults and vestibular patients.

INTRODUCTION

The normal balance system is a complex unit of three major sensory system inputs (proprioception, vision, and vestibular) integrated and used to coordinate muscles for movement control (Cohen, 1994; Black, 2001). Reduction in these sensory inputs can alter one's ability to control movement and maintain balance, causing falls. Unexplained falls often impair daily life function (Sattin, 1992) and are associated with reduced balance and mobility in older individuals over 65 years of age (Walker & Howland, 1991). Although all three sensory inputs are integrated and important for humans to remain upright (Szturm, Ireland, & Lessing-Turner, 1994), this manuscript will focus on vestibular inputs, as the symptoms of vestibular disorders (i.e., vertigo, disequilibrium, disorientation, and blurred vision) may lead to an unexplained fall without compensatory actions (Walker & Howland, 1991).

Normal age-related declines in vestibular function and balance skills (Paige, 1989; Cohen, Heaton, Longdon, & Jenkins, 1996) may affect the ability of older adults to compensate for dizziness caused by their deteriorating vestibular system (Baloh & Honrubia, 1990). Dizziness, a frequent problem among older adults, is a common complaint of persons over 75 years of age (Sloane, Blazer, & George, 1989). In the older population, dizziness is associated with functional declines (Boult, Murphy, Sloane, Mor, & Drone, 1991) and injuries from falling (Lawson, Fitzgerald, Brichall, Aldren, & Kenny, 1999), the latter of which may lead to morbidity and mortality (Tinetti, Liu, & Clays, 1993). In fact, while a fall may have a negative impact on the physical functioning of an older individual (Yardley & Smith, 2002), fear of falling, a common report of anxiety among older adults (Howland, Peterson, Levin, Fried, Pordon, & Bak, 1993) is associated with decreased function/health, balance, mobility, and activity levels, as well as higher levels of handicap, poorer quality of life, and psychological distress (Tinetti, Mendes de Leon, Doucette, & Baker, 1994). Some have estimated the prevalence of this fear among community-dwelling older people up to 55% (Tinetti et al, 1994).

Dizziness due to vestibular disorders is also significantly associated with falling (Brocklehurst, Exton-Smith, Lempert Barber, Hunt, & Palmer, 1978; Sixt & Landahl, 1987; Colledge, Barr-Hamilton, Lewis, Sellar, & Wilson, 1996; Lawson et al, 1999; Whitney, Hudak, & Mardretti, 2000; Herdman, Blatt, Schubert, & Tusa, 2000) and fall related injuries (Lawson et al, 1999). While most patients with vestibular disorders are over the age of 65 years, impairment of the vestibular system can occur at any age (Brocklehurst et al, 1978). Signs and symptoms of chronic peripheral vestibular disorders include persistent vertigo, postural imbalance or disequilibrium, disorientation, and instability of gaze during head movements or blurred vision (Baloh & Honrubia, 1990; Szturm et al, 1994). However, signs and symptoms of vestibular disorders vary across individuals and, more specifically, may depend on whether the lesion is peripheral or central and unilateral or bilateral (Shepard & Telian, 1994).

Since common terms to explain vestibular function are balance and equilibrium, it is not surprising that to test vestibular function clinicians include tests of posture control with those for vestibular labyrinth function (Cohen, 1994; Herdman, 1997a). These primary clinical balance tests are used to identify those with vestibular deficits, but do not reveal the true functional impairment of vestibular patient behavior (Cohen, 1994). In fact, only a few studies have identified the functional deficits exhibited by these patients. The major functional deficits reported by vestibular patients prior to rehab included cleaning, gardening, rolling over in bed, lying down, getting out of bed, standing up, driving, transferring out of a car, bathing, climbing stairs, and walking on even surfaces, uneven surfaces, or long distances (Cohen, 1992). These self-reports demonstrate a functional disability pre-rehab and a significant improvement in these same tasks post-rehabilitation.

Spontaneous recovery, or central compensation, of the symptoms of a vestibular disorder should theoretically occur within ninety days of the onset of the disorder (Gans, 1999). However, too often, particularly in those with sudden-onset vestibular diseases, some patients never experience, and thus do not benefit from spontaneous central compensation (Gans, 1999). Therefore, vestibular rehabilitation

(VR) exercises are thought to be important in the management of vestibular patients (Nashner, 1997; Gans, 1999; Gans 2001). Present day accepted protocols have been modified to be administered at home or in the clinic directed by a medical provider and are designed to improve gaze and postural stability via increased head movement and facilitation of visual and somatosensory cues of balance. See Appendix D for 10 clinically acceptable at-home VR exercises (Gans, 2001). These exercises are designed to be altered to the individual, treating the particular dysfunction of each patient (Gans, 1999; Gans, 2001). Gans (1999; 2001) and Herdman (1997a, b) described two diagnosis-based strategies which are suggested for rehabilitation: adaptation and substitution exercises. Adaptation exercises consist of task-oriented repetitive eye-head movements and are designed to enhance eye stabilization during rapid head movement (vestibulo-ocular reflex, VOR) and ameliorate symptoms caused by an asymmetry in the vestibular system. Substitution exercises consist of repetitive eye-head movements during ambulation or other whole body movement tasks and are designed to enhance postural stability and equilibrium by encouraging alternative compensation of the remaining sensory systems, vision and proprioception, on which the patient must rely to maintain balance.

Unfortunately, patient compliance for VR can be problematic. One reason for this is because unilateral vestibular patients try to avoid rapid, repetitive eye and head movements, thus exacerbation of the associated symptoms (Cohen, 2004). To increase compliance in this regard clinicians and researchers suggest the inclusion of more functional and meaningful tasks into the rehabilitation program such as playing Frisbee or catch (Cohen Kane-Wineland, & Miller, 1995), where head movement occurs naturally and is not the explicit goal of the task. Although clinician driven therapy produces better results than home based therapy (Kao, Chen, Chern, Chen, & Hwang, 2009), patient concerns exist for travel to the clinic and spending for out-of-pocket medical expenses. Thus when utilizing an exercise program at home, such as the exercises described in Appendix D, patients are not closely monitored and the amount of time spent on for therapy may take longer partially because patients may not be performing the exercises appropriately to gain the full benefit of VR. Investigations of a more efficient VR protocol, in which performance of the most effective exercises would take less time, may increase patient compliance and lead to more successful VR outcomes for increasing physical function and quality of life.

Accounting for age of the patient is also important when assessing vestibular rehabilitation. Unfortunately, with the normal aging process, regardless of the presence or absence of a vestibular pathology, there is a decline in the visual (Sekuler, Hutman, & Owsley, 1980), proprioceptive (Skinner, Barrack, & Cook, 1988), and vestibular (Linthicum, 1989) systems. Because these normal aging declines accompany declines in balance abilities (Sekuler et al, 1980; Skinner et al, 1988), one can hypothesize that central compensation during vestibular rehabilitation of an elderly patient may be different than that of a younger vestibular patient (Cohen, Kimball, & Adams, 2000). Therefore, it is reasonable to postulate that elderly patients with a vestibular impairment may have more difficulty in environmental situations in which the visual input or support surfaces are compromised or manipulated as compared to their normal older peers or the young vestibular patient. Undoubtedly, proper assessment of vestibular rehabilitation needs to incorporate the aging effect (Cohen, 1994; Shepard & Telian, 1994; Cohen, Kimball, & Jenkins, 2002). Because VR therapy is designed to alleviate symptoms and improve balance and mobility, is thought to also help reduce anxiety and activity avoidance related to the fear of falling (Luxon & Davies, 1997). Therefore, the implementation of VR could aid in increasing independence and decreasing disablement in older adults with and without known vestibular dysfunction.

Anecdotal evidence and self-reports of patients with chronic peripheral vestibular disorders suggest that vestibular rehabilitation dramatically improves daily life skills necessary for maintaining independence and postural control as determine by improved scores on the Vestibular Disorders Activities of Daily Living (VADL) (Cohen,1992; Cohen et al, 1995; Cohen & Kimball, 2000, Cohen et al, 2000; Cohen & Kimball, 2004) and on the Dizziness Handicap Inventory (DHI) (Johansson, Akerlund, Larsen, & Andersson, 2001; Meli, Zimatore, Badarocco, De Angelis & Tufarelli, 2006; Horning & Gorman, 2007). In addition to qualitatively evaluating daily life skills to exemplify the success of vestibular rehabilitation, primary clinical balance tests are used as accurate measures of pre- and post-treatment results of vestibular rehabilitation (Black, 2001; Badke, Miedaner, Grove, Shea, & Pyle, 2005; Perez, Santandreu, Benitez, & Rey-Martinez, 2006). While these tests may be a good assessment of the balance system and may reveal physiological impairments of the three sensory systems of the balance system (Goebel JA, Sataloff RT, Hanson JM, Nashner LM, Hirshout DS, & Sokolow CC , 1997), objective clinical assessments of improvement in daily life function as a result of vestibular rehabilitation are limited.

Physical performance measures during activities of daily living (ADL) are beginning to emerge and replace self-reported functional assessments to test a person's level of independence and disablement. The self-reported assessments are quick and require minimal to no training for proper administration (Wasson, Keller, Rubenstein, Hays, Nelson, & Johnson, 1992), but the reliability of outcomes are also questioned (Fried, Ettinger, Lind, Newman, & Gardin, 1994). In the field of vestibular rehabilitation, evidence of self-perceived improvement in independence and daily life function exists (Cohen, 1992; Cohen, 1994; Cohen & Downs, 1996; Cohen & Kimball, 2000; Cohen et al, 2000; Cohen & Kimball, 2004; Meli et al, 2006; Horning & Gorman, 2007), while empirical evidence of functional improvement during ADLs as a result of vestibular rehabilitation is sparse (Johansson et al, 2001) and is limited to assessments that would be performed in an occupational therapy (Cohen & Kimball, 2004; Cohen, 2004) or a physical therapy clinic. These include the Dynamic Gait Index (Meli et al, 2006; Horning & Gorman, 2007) and the five times sit to stand test (Meretta, Whitney, Marchetti, Sparto, & Muirhead, 2006). Furthermore, a self-administered scale has several confounding limitations in terms of self-efficacy, such as self-perceived ability being different than actual ability (Brown, Moore, Hemman,

& Yunek, 1996; Mendel, Bergenius, & Langius, 1999), personality factors, psychological needs, previous illness or disabilities, and demands of attention or care from significant others (Cohen & Kimball, 2000). For instance, a young mother with mild vertigo may perceive herself to be less independent when caring for her newborn than an elderly woman with moderate vertigo, who perceives herself to be independent but inconvenienced when caring for her chronically ill husband. In this comparison diagnostic assessments might reveal the young woman to have a much less severe vestibular impairment than the self-reported “more independent” elderly woman (Cohen & Kimball, 2000). Moreover, when determining level of independence among vestibular disorder patients using the Vestibular Disorders Activities of Daily Living (VADL), patients labeled themselves more independent than their significant others’ perceptions labeled them (Cohen & Kimball, 2000). Undoubtedly, future studies to determine if subjective reports of independence and physical function among vestibular patients, as assessed by the VADL, are the same as objective independence and physical function results (Cohen & Kimball, 2000), as assessed by a valid physical function tool (i.e., clinical balance tests, Continuous Scale of Physical Functional Performance--CS-PFP-10, etc.) are needed. Examining subscale scores of subjective and objective assessments of physical function would give insight to ADL task performance.

Furthermore, analyzing kinematic strategies utilized by young and older normal subjects and peripheral vestibular patients during the vestibular rehabilitation exercises should give insight to specific movements needing more or less rehabilitative attention for the given population. For instance, previous research on kinematic measures have discovered that vestibular patients prior to VR exhibit altered whole body movement performance, such as an ataxic gait (Herdman, 1997b) and a slower pace and higher step number during gait tasks (Cromwell, Schurter, Shelton, & Vora, 2004, Perring & Summers, 2007; Paquet, Dannenbaum, Hakim-Zadeh, & Fung, 2006). Vestibular patients also demonstrate differences in kinematic performance of head movements, such as having a restricted range of motion

(Cromwell et al, 2004; Cohen, 2004), altered (Pozzo, Berthoz, Lefort, & Vitte, 1991; Kubo, Kumakara, Hirokawa, Yamamoto, Imai, & Hirasaki, 1997; Mamoto, Yamamoto, Imai, Tamura, & Kubo, 1992; Keshner & Dhaher, 2008) and inconsistent head movements patterns (Patten, Horak, & Krebs, 2003), and slower performance of head movements (Paquet et al, 2004; Paquette, Paquet, & Fung, 2006; Cohen, 2004). In terms of temporal aspects of kinematic performance, recent research has demonstrated that vestibular patients have exhibited improved performance which was related to improved function, as determined by perceived functional measures and/or clinical assessments (Cohen, 2004; Cohen & Kimball, 2004; Meretta et al, 2006; Perring & Summers, 2007). One can hypothesize that the examination of behavioral kinematics used by normal subjects and chronic peripheral vestibular patients during the vestibular rehab exercises, as well as an objective measurement of functional performance pre-rehabilitation, could lead to a more efficient VR protocol, better patient compliance, thereby aiding in the advancement of vestibular rehabilitation. Moreover, advances in VR would clearly benefit those with vestibular disorders and may also explain falls in the elderly population due to vestibular system degradation, which is known to occur with age (Linthicum, 1989).

Research on the movement strategies used during performances of VR exercises and the effect of rehab on daily life function of those with vestibular dysfunction may be of great value in advancing vestibular rehabilitation. In this regard, the intent of the review of literature associated with this manuscript was to present the necessary background information concerning the balance system, the function of an abnormal vestibular system, a quantitative assessment of physical functional performance, and an overview of vestibular rehabilitation and how it is presently assessed (see Chapter 2). Based on this information, a study comparing the movement strategies and functional performance of young and old subjects with no known neurological deficits to pre-rehabilitative patients with a chronic peripheral vestibular disorder was designed. After diagnostic differences among control subjects and patients were identified, research on the kinematic strategies used during VR exercises and functional assessments were performed. Results of these experiments added to our understanding of movement strategies used by the different subject groups.

The *first purpose* of the present study was to assess physical functional levels of vestibular disorder patients at the pre-rehabilitation stage and young and older control subjects. Relationships between the subjective (Vestibular Disorders Activities of Daily Living - VADL and the Dizziness Handicap Inventory - DHI) and objective (Continuous Scale of Physical Functional Performance - CS-PFP-10) assessments of activities of daily living across subject groups and within older adults and patients were examined. The *second purpose* of the present study was to describe various movement kinematics used during performance of 10 vestibular rehabilitation exercises and make comparisons across groups. Comparisons were made among patients with a history of chronic vestibulopathy with no history of VR and young and older controls. The *final purpose* of the present study was to examine the relationship between the movement kinematics used during the 10 rehabilitative exercises and physical functional level, according to each patient and/or control subjects' DHI, VADL, and CS-PFP-10 scores.

Hypotheses

This study was designed to analyze different aspects of VR exercises to aid in rehab advancement with a future intent to decrease the rate of unexplained falls. In order to better understand the differences between subjective and objective measures of physical function and independence among the three groups, individual subject means for subjective scales (VADL, DHI) and objective assessment (CF-PFP) scores of physical function were determined. Based on the evidence that self-perceived independence during daily life activities decreases in vestibular patients pre-rehab (Cohen 1992; Cohen, 1994; Cohen et al, 1995; Cohen & Kimball, 2000), we expected that the patient group with no previous rehabilitation would demonstrate lower total performance on the VADL, DHI, and CS-PFP-10 as compared to control subjects ($\text{VADL}^{\text{patient}} > \text{VADL}^{\text{control}}$; $\text{DHI}^{\text{patient}} < \text{DHI}^{\text{control}}$; $\text{CS-PFP-10}^{\text{patient}} > \text{CS-PFP-10}^{\text{control}}$). Given the previous research regarding relationships between subjective and objective assessments of physical function in vestibular patients, we expected that correlations between the subjective, VADL and DHI, and objective, CS-PFP-10, assessments of physical function would exist.

In order to better understand VR in terms of the specific exercises (i.e. determining which exercises produce patient or aging effects) specific kinematic variables across peripheral vestibular patients and young and old healthy subjects for each exercise were compared. Based on evidence that vestibular patients use different coordination strategies when performing whole body reaches (Daghestani, Anderson, & Flanders, 2000) and possess a more ataxic gait (Herdman, 1997b) than the control subjects, it was hypothesized that kinematic differences will exist between the non-rehabilitated patient group and the other groups (kinetic variable$^{\text{patients}}$ $\neq$ kinetic variable$^{\text{controls}}$) for exercises which challenge the vestibular patients’ movements (i.e. those involving quick head movements and challenge upright posture).

Comparisons among kinematic variables while performing vestibular rehab exercises will help identify movement differences for subjects performing these specific tasks. Identifying links between kinematic measurements and perceived or actual ADL abilities are expected to offer greater insight into how kinematic performance of the exercises relates to function. Therefore, the relationships between the performances used during the 10 rehabilitative exercises and physical functional level, according to perceived (DHI/VADL) and actual (CS-PFP-10) function scores, will be identified for each exercise. Based on the limited findings for altered coordination (Daghestani et al, 2000) and gait (Herdman, 1997b; Cohen & Kimball, 2004) and the decreased self-perceived independence during daily life activities (Cohen 1992; Cohen, 1994; Cohen et al, 1995; Cohen & Kimball, 2000; Cohen & Kimball, 2004) by vestibular patients, it was hypothesized that kinematic measurements with patient effects would be linked to poor performance on ADL tasks as assessed by functional measurements.

REVIEW OF LITERATURE

The Normal Balance System

Unexplained falls that occur more frequently in adults over the age of 65 years can impair daily life function and are one of the leading causes of death in the aging population (Sattin, 1992). Two of the major risk factors of unexplained falls in the elderly are reduced balance and mobility (Walker & Howland, 1991). While the primary goal of the normal balance system in humans is to remain upright (Szturm et al, 1994), the functional goals of a normal balance system are limited to motor output coordinated by the proprioceptive, visual, and vestibular systems (i.e., the major sensory systems used for maintaining balance). Three functional goals of the normal balance system are: (1) to rapidly reposition the body's center of mass over the base of support to prevent a fall; (2) to accurately perceive the body's speed and direction of movement and its position in the environment; and (3) to maintain control of the ocular muscles for proper gaze stabilization of a clear image in the external world while the body and/or environment are in motion (Shepard & Telian, 1994). Clearly, these goals are best achieved in a normal, healthy, and perhaps younger person.

In the normal functioning body, movement control depends on continuous and accurate information from the proprioceptive system (Spirduso, 1995). The proprioceptive system, which contributes to somatosensation, is used to trigger spinal reflexes needed to make rapid postural adjustments in order to maintain balance/postural control. Information about body position is gathered from the skin, joint, and muscle receptors. One of the most valuable attributes of the proprioceptive system is that it commonly relies on reflexive control (Spirduso, 1995). Thus, corrective movements can be performed before the individual perceives a problem such as imbalance.

The visual and vestibular systems also contribute to body positioning. In addition to providing information about limb position, the visual system provides information about the body's position in space, the speed of the body's movement, and the objects in the surrounding environment. On the other hand, the vestibular system may be thought of as the internal reference of the position of the head in space that provides a person with information about linear and angular head acceleration. When combined, the multiple inputs from vestibular, proprioceptive, and visual systems can be integrated and used to direct balance control (Shepard & Telian, 1994).

The interaction among the three sensory systems used for balance also guide future decisions of balance and mobility (Shepard & Telian, 1994). For instance, the vestibular labyrinths have neuronal connections to the eye, influencing eye movements with the vestibulo-ocular reflex, and to the spinal cord influencing trunk and limb movements through vestibulo-spinal projections. Thus, the vestibular apparatus is responsible for keeping the eyes fixed on a target while the head is moving, either horizontally, vertically or during rotations (Spirduso, 1995). As one is walking and trying to keep his/her gaze stabilized on a target, cutaneous and muscular cues from ambulation are gathered in the proprioceptive system. Thus, while vestibular and proprioceptive cues indicate changes in head movement, the visual system identifies objects in the environment and gathers information about the body’s position in space. Simultaneously, the vestibular system constantly compares its internal information about head position to the visual and proprioceptive cues. Although each system has defined responsibilities, which may overlap with the other systems, this entire complex example of the integration of the three sensory systems demonstrates how humans maintain balance (Shepard & Telian, 1994). Moreover, stability disorders may result from a deficit in one or more of the three major sensory inputs of the balance system (Shepard & Telian, 1994).

The complex interaction among sensory systems to maintain balance exemplifies the obvious redundancies within the central nervous system (CNS). In the balance system, the necessary sensory inputs converge to a common central processor, which after processing the information, results in motor output contributions to an adaptive feedback loop and to help maintain static and dynamic balance in the environment. For instance, in order to complete a simple task, such as gaze stabilization (i.e., through the vestibulo-ocular reflex - VOR), after angular acceleration of the horizontal semi-circular canals, vestibular input from the receptor hair cells within the horizontal semi-circular canals sends signals to the vestibular nuclei. Information from the neurons in the vestibular nuclei converges with other information (e.g., proprioceptive information of eye position) in the common central processor (i.e., the medial longitudinal fasciculus) and transmits eye movement information to the effector neurons in the corresponding ocular nuclei, resulting in contraction of specific ocular muscles to deviate the eyes opposite to head rotation (Honrubia & Hoffman, 1997). Such a pathway enables the CNS to adapt to or compensate for a loss or challenge to one of the three sensory modalities of the balance system (Honrubia & Hoffman, 1997). For instance, the classic "moving room" experiment by Lee and Aronson (1974) demonstrates the strong reliance humans have on vision during daily activities. The authors observed the normal subjects' postural responses while standing in a room with a stationary floor yet with walls that could move forward and backward. Subjects made postural adjustments in accordance with the wall movement to maintain upright stance or relatively static balance. Because the visual information was incorrect and induced a postural sway, correct information from the proprioceptive and/or vestibular cues must have signaled the central nervous system (CNS) to correct for a potential loss of stability. Wade and colleagues (1995) elaborated on this experiment and found that elderly subjects were more susceptible to increased sway in the "moving room", thereby demonstrating an even greater reliance on vision for posture control in older adults.

This interaction between the visual, proprioceptive, and vestibular systems is also exemplified through the Romberg test, a well-known clinical screening to assess somatosensation (Romberg, 1853). Romberg noted that somatosensation dominates human postural control when a patient is standing on a fixed support surface with the eyes closed. If postural sway should increase during the eyes closed condition relative to the eyes opened condition, this is suggestive of a somatosensory dysfunction and a dependence on the visual system, which is the primary back-up sensory system during somatosensation disruption (Romberg, 1853).

The most obvious example of the redundancies existing among the sensory systems for balance control may be observed in the Sensory Organization Test (SOT) of Computerized Dynamic Posturography (CDP) when the visual and proprioceptive systems are challenged in a clinical setting. CDP is known to effectively assess postural control, in documenting improvement of postural control following vestibular rehabilitation (Black, 2001). According to Black (2001), CDP actually measures the relative contribution of each of the three sensory systems – proprioception, vision, and vestibular – to overall balance primarily through the sensory organization test (SOT). During the six conditions of the SOT, peak-to-peak magnitude and total amount of anterior-posterior body sway are measured. Amounts are measured as the horizontal anterior-posterior displacement between center of mass and center of pressure. The patient stands on movable footplates surrounded by a three-sided visual display while securely attached to a supported safety harness. In the six test conditions, the isolation of each sensory system is accomplished by altering the movement or lack of movement of the footplates and/or the visual display while the patient's eyes are open or closed resulting in six test conditions (Shepard & Telian, 1994; Black, 2001). Note that when the eyes are closed (SOT 2 and 5) or the visual display moves with the subject (SOT 3 and 6), the visual system is rendered unreliable. If the footplates move with the subject (SOT 4, 5, and 6), proprioceptive cues provide incorrect input and are also deemed unreliable. Thus, because conditions SOT5 and SOT6 provide the greatest challenge to the vestibular system, the subject must rely on this system to maintain standing balance (Black, 2001; Cohen et al, 1995). In fact, during stance in a normal setting the vestibular labyrinths may act as an internal reference against which visual and proprioceptive cues are compared to guide future decisions of balance and mobility (Barin, 1987). When a conflict arises between the internal reference and the two remaining sensory systems, normal subjects will demonstrate increased anterior-posterior sway while their vestibular patient counterparts will have abnormally increased sway or will fall (Cohen et al, 1995: Black, 2001). In summary, a challenge or damage to at least one sensory system of balance should result in either a physiologic representation of a sensory conflict (Shepard & Telian, 1994) or compensation by a back-up sensory modality of balance to adapt to the new situation (Romberg, 1853; Cohen et al, 1995; Black, 2001).

Function of an Abnormal Vestibular System: Vestibular Disorders

While the three major sensory systems of balance work together, vestibular disorders cause the majority of balance disorders and are rarely properly diagnosed and/or treated ineffectively (Gans, 1999; Gans, 2001). As stated previously, difficulty with the maintenance of balance is one of the greatest risk factors for unexplained falls in the elderly (Walker & Howland, 1991). Dizziness and vestibular disorders are significantly associated with falling (Brocklehurst et al, 1978; Sixt & Landahl, 1987; Colledge et al, 1996; Lawson et al, 1999; Whitney et al, 2000; Herdman et al, 2000) and fall related injuries (Lawson et al, 1999). While most patients with vestibular disorders are over the age of 65 years, impairment of the vestibular system can occur at any age (Brocklehurst et al, 1978). Signs and symptoms of chronic peripheral vestibular disorders, from a clinical standpoint, include persistent vertigo, postural imbalance or disequilibrium, disorientation, and instability of gaze during head movements or blurred vision (Baloh & Honrubia, 1990; Szturm et al, 1994). However, signs and symptoms of vestibular disorders vary across individuals and, more specifically, may depend on whether the lesion is peripheral or central and unilateral or bilateral (Shepard & Telian, 1994). See Appendix B for a detailed audiology case history form used with vestibular patients to gain information about their symptomology.

Unilateral and bilateral peripheral vestibular disorders exhibit different signs and symptoms (Fox & Cohen, 1993). Therefore, to properly treat each, one must understand their corresponding symptoms (Shepard & Telian, 1994). Vertigo, a symptom most commonly associated with vestibular disorders, can be described as the hallucination of self-motion while the person is actually lying or sitting still. It is commonly indicative of a unilateral disorder resulting from vestibular nystagmus, a left and right repositioning of the eyes, involving a slow and quick phase which are opposite in direction (Shepard & Telian, 1994). This is not surprising since vertigo and vestibular nystagmus are caused by an inequality of the signals from the right and left vestibular apparatus ascending to the vestibular nuclei (Fox & Cohen, 1993; Shepard & Telian, 1994; Gans, 1999; Gans, 2001). Because a unilateral disorder is defined by damage to one area in only one of the two vestibular labyrinths, asymmetrical input from the left and right sides is inevitable, as one labyrinth sends a weak output signal (Fox & Cohen, 1993; Gans, 1999; Gans, 2001). Patients with unilateral disorders may exhibit vertigo with a stationary head and/or during active head movement (Shepard & Telian, 1994). Bilateral vestibular disorders, on the other hand, result in two weak or obliterated portions of the vestibular system. This causes symmetrical yet little to no input from either vestibular apparatus (Fox & Cohen, 1993). Because there is no asymmetry in ascending signals, vertigo will not occur. Therefore, symptoms of a bilateral peripheral lesion typically include disequilibrium, increased difficulty in mobility while in darkness, increased imbalance while walking on uneven surfaces, but not vertigo (Fox & Cohen, 1993).

While standing still in a well-lit room, one with a vestibular disorder may be considered normal because s/he may do so without imbalance. Just as people without neurological deficits rely on a back-up sensory system during disruption of one sensory system (Romberg, 1853; Cohen et al, 1995; Black, 2001), patients with vestibular disorders gain a strong dependence on the visual and proprioceptive systems to compensate for the reduction or loss of vestibular function (Shepard & Telian, 1994). Most studies claim that normal subjects (Lee & Aronson, 1974), but particularly vestibular patients (Spirduso, 1995; Shepard & Telian, 1994; Black & Nashner, 1985; Black & Nashner, 1986), are more reliant on vision than proprioception. For example, a patient with a bilateral vestibular disorder may successfully step from a fixed support surface, such as a cement patio, to an uneven somewhat soft support surface, such as a grass lawn, in a well-lit environment with no difficulty. However, the bilateral vestibular disorder patient is pre-disposed to falling in darkness. When proprioception is compromised, the utilization of visual and vestibular inputs will normally increase. In this case, however, the bilateral vestibular disorder patient may only rely on visual inputs. Therefore, the removal of the visual information from daylight to darkness severely limits the patient with a bilateral deficit on the unpredictable support surface (Shepard & Telian, 1994). It has been suggested that the over-reliance on vision, particularly in bilateral vestibular patients, may be because movement of the visual environment (optical flow) has been shown to be a big contributor to the body's anterior-posterior body sway, thus may trigger postural reflexes similar to the vestibular system (Lee & Aronson, 1974), especially in the elderly (Wade, Lindquist, Taylor, & Treat-Jacobson, 1995; Spirduso, 1995).

Vestibular and Balance Assessment

Because of the complexity and integrated nature of the balance system, an evaluation of only one sensory system would not give a clear indication of the patient's overall stability (Shepard & Telian, 1994). Incorporating assessments, which evaluate the three major sensory systems of equilibrium should give one a better view of the entire balance system, rather than just the vestibular apparatus, and should point to the system causing the decline in the patient's stability (Cohen, 1994; Shepard & Telian, 1994). Since the function of the vestibular system is highly integrated with postural control (Baloh & Honrubia, 1990) and control of eye movement (i.e., the VOR), most researchers, as well as clinicians, evaluate posture and eye movement control in addition to labyrinth canal function as measurements of vestibular system function (Shepard & Telian, 1994; Cohen, 1994). To best achieve proper evaluation of the balance system, vestibular patients are classified by group with results from the three primary diagnostic assessments: CDP to test all three systems (Shepard & Telian, 1994; Nashner, 1997; Black, 2001), sinusoidal harmonic acceleration (SHA) in darkness to test the VOR (Cohen, 1994), and alternate bithermal binaural calorics of the horizontal semicircular canals to test for physiologic function of each horizontal semi-circular canal of the vestibular system (Shepard & Telian, 1994; Cohen et al, 1995; Herdman, 1997a; Cohen et al, 2000). Details of each assessment are provided below.

Assessments of Postural Control

As mentioned previously, the SOT of CDP accurately assesses postural control, reliably document improvement of postural control post-vestibular rehabilitation treatment, and measures the relative contribution of each of the three major sensory systems of balance. During two of the six SOT conditions (SOT5 and SOT6), the subject's visual and proprioceptive systems are challenged via altered visual conditions (i.e., movement of a three-dimensional visual display or eyes closed) and altered support surfaces (i.e., footplates that move with the body), consistently providing the greatest challenge to the vestibular system. These two conditions result in increased sway in normal subjects, compared to upright stance (SOT1), yet the most prominent increases in sway are demonstrated in those with vestibular deficits (Cohen et al, 1995; Black 2001). Note that patients with vestibular impairments who have undergone vestibular rehabilitation consistently demonstrate improvement in postural control (i.e., decreased sway) during conditions SOT5 and SOT6 (Cohen et al, 1995). According to Cohen and her colleagues (1995), balance control improvements noted during the more challenging conditions (SOT5 and SOT6) compared to less challenging conditions (SOT1 and SOT2), may suggest that subjects have either learned to utilize their residual vestibular input to resolve sensory conflicts or that subjects have adopted alternate strategies to maintain static balance.

Due to the extreme financial constraints imposed by implanting CDP in a standard otorhinolaryngology or audiology practice, clinicians may choose to utilize an alternative assessment of human postural control (Horak, 1987; Shumway-Cook & Horak, 1986; Cohen, 1994). Some alternatives, such as the well-known "Foam & Dome", also known as the Computerized Test of Sensory Integrated Balance (CTSIB), continue to objectively measure postural sway on moveable footplates while the patients are either standing on a hard or dense foam surface with his or her eyes open, closed, or covered by a dome-shaped head piece (Cohen, Blatchly, & Gombash, 1993; Shumway-Cook & Horak, 1986). Subjective measures of postural sway also exist (Cohen, 1994; Shepard & Telian, 1994). Although there is increasing uncertainty in the reliability of qualitative interpretation of postural control across clinics (Shepard & Telian, 1994), it has become more widely accepted to substitute various means of assessment of anterior-posterior sway for the footplates (Cohen, 1994; Shepard & Telian, 1994). An example of such a subjective assessment is the Gans Sensory Organization Performance (SOP), which measures postural control in seven conditions via a combination of the Romberg (Romberg, 1853), the “Foam & Dome” test, or CTSIB (Cohen et al, 1993; Shumway-Cook & Horak, 1986), and the stepping Fukuda (Fukuda, 1959; Bonanni & Newton, 1998). Like the CDP, the Gans SOP assesses the relative contribution of the three sensory systems of balance. Clinicians subjectively rate the level of anterior-posterior sway while the patient is standing on a hard surface with feet shoulder-width apart (SOP 1 and 2) or in the tandem position (SOP 3 and 4) or standing on a dense foam pad (SOP 5 and 6). Performing these tasks with either the eyes open (SOP 1, 3, and 5) or closed (SOP 2, 4, and 6) produces six conditions to evaluate (Gans, 1999; Gans 2001). The seventh condition consists of the stepping Fukuda in which the patient marches in one place with the eyes closed (Fukuda, 1959; Bonanni & Newton, 1998). The examiner then notes the existence and/or direction of sway during the first six conditions (Gans, 1999; Gans, 2001) and notes whether the patient veers to the right or to the left during the seventh condition, the Stepping Fukuda (Fukuda, 1959; Bonanni & Newton, 1998; Gans, 1999; Gans, 2001). In summary, subjective assessments of postural control, such as the Gans SOP (Gans, 1999; Gans, 2001), are deemed to be useful screening tools and/or therapeutic assessments of balance difficulties in patients with vestibular dysfunction and in elderly individuals (Cohen et al, 1993; Shumway-Cook & Horak, 1986).

Assessments of the Vestibulo-Ocular Reflex

The second clinical vestibular function test, sinusoidal harmonic acceleration (SHA) performed at a low frequency, in darkness, is used to effectively assess the VOR (Cohen et al, 2002). The function of the VOR is to stabilize the eyes during rotational head movements. Clinicians and researchers have tested the reflex by monitoring eye movements during sinusoidal head movement. For example, if the eyes move to the right at the same speed as a head movement to the left, the reflex is functioning properly (Shepard & Telian, 1994). Utilizing electro-oculography and a computerized rotational chair, with the patient's head securely fixed at a 30^o angle toward their chest, the patient is rotated sinusoidally at 0.0125 Hz while his/her eye and head movements are recorded.

The following is a brief verbal description of each parameter of SHA, and common results, as they relate to certain vestibular disorders. Phase, gain and asymmetry are the parameters evaluated to measure the VOR (Shepard & Telian, 1994). *Phase* represents the continuous time relationship of the eye movement relative to the head movement, where eye velocity is very close to, or slightly lags, head velocity in a normal functioning system (Shepard & Telian, 1994). Also, in a normal functioning system, *gain*, the absolute ratio of the average slow-component velocity of the eye to the average slow-component velocity of the head, is close to one, and *asymmetry,* the difference between the slow-component velocities of the rightward and leftward accelerations of the chair, is approximately 100% (Shepard & Telian, 1994). Abnormal results for unilateral vestibular patients would include an increase in phase, a decrease in gain, and a large asymmetry between rightward and leftward rotations (Cohen et al, 2002). Abnormal results for bilateral vestibular patients would include absent VOR responses in eye movements associated with reduced gain and no asymmetry, reduced gain with the possibility of normal gain at higher rotation frequencies, and inconsistent responses in all parameters associated with no clear nystagmus at any oscillation frequency (Stockwell & Bjorab, 1997). Phase values are not commonly plotted for bilateral vestibular patients due to low frequency response gains (Stockwell & Bjorab, 1997).

Rotational testing assesses the VOR of the horizontal semi-circular canals at stimulus frequencies at least one octave higher than that of other tests, or > 0.004 Hz. Therefore, it adds great value to overall balance assessment due to stimuli more comparable to every day function and because of this is considered the choice procedure in the evaluation of patients with suspected bilateral vestibular disorders (Cohen & Gavia, 1998). One limitation of such testing is its inability to lateralize a peripheral vestibular lesion, particularly in the lack of an asymmetry toward the site of lesion in chronic cases (Stockwell & Bjorab, 1997). Apparently, a stronger rotatory stimulus, such as 0.25 Hz with a peak velocity up to 300^o/sec, may demonstrate consistent asymmetries in patients with chronic unilateral peripheral lesions (Paige, 1989). However, a rotation device with this power and the analysis of such an extreme rotation presents major technical difficulties for the clinician and tolerance problems for the patient (Stockwell & Bjorab, 1997).

High frequency headshakes, which may be recorded on standard electro-oculography (EOG) equipment, are an alternative to the SHA to assess the VOR and horizontal semi-circular canal function at higher stimulus frequencies (Schmid & Zambarbieri, 1992). With eyes open, the patient's head is tilted 30^o forward and rotated along the long axis passively (i.e., with assistance from the examiner) or actively (i.e., with no assistance), in time with an auditory stimulus (Schmid & Zambarbieri, 1992; Goebel, 1990). The phase, gain, and asymmetry of eye movements are analyzed similar to that of SHA (Fineberg, O'Leary, & Davis, 1987; O'Leary & Davis, 1989; O'Leary & Davis, 1990), while the maximum slow phase velocity, duration, and latency of nystagmus are also recorded at the conclusion of the head rotations when performing high-frequency headshakes (Hain, Fetter, & Zee, 1987; Gans, 2001). This after-nystagmus is caused by an imbalance of the velocity storage mechanism, which helps to regulate the rate at which the excitation and inhibition of the vestibular neurons return to their resting state (Hain et al, 1987; Gans, 1999; Raphan, Matsuo, & Cohen, 1979) and may also be assessed subjectively as a screening tool by simply observing the presence and fast-phase direction of expected eye movements.

Assessment of Horizontal Semi-Circular Canal Function

Alternate bithermal binaural caloric irrigation, the last clinical test used to classify vestibular patients, measures the responsiveness of one horizontal semi-circular canal relative to the other (Shepard & Telian, 1994) and is analogous to a head rotation frequency of 0.003 Hz (Hamid, Hughes, & Kinney, 1987). The purpose of the caloric testing is to produce a convection effect on the endolymph, creating a fluid flow that stimulates one horizontal semicircular canal and causes an asymmetry between the signals ascending to the brain. To deliver the appropriate volume of temperature-changing stimulus to the tympanic membrane, the clinician may choose an air or water caloric irrigator. Both systems have their advantages and disadvantages while the financial cost is similar (Jacobson & Newman, 1997). During the caloric stimulation, regardless of irrigation stimulus type, the eyes are closed, and the head is elevated 30^{o} from supine to prompt the optimum force of the convection current on the receptors at the base of the vertically oriented horizontal canal (Coats & Smith, 1967). The cool or warm change to the endolymph will result in the hyperpolarization or depolarization, respectively, of the hair cell receptors within the horizontal canal of the stimulated ear (Jacobson & Newman, 1997). This asymmetry of ascending signals to the brain results in stimulation of the VOR causing vestibular nystagmus and, commonly, mild vertigo (Shepard & Telian, 1994; Jacobson & Newman, 1997). As stated previously, vestibular nystagmus is a left and right repositioning of the eyes, involving a slow and quick phase which are opposite in direction. Table 1 details the caloric-induced physiological and perceived responses in the normal functioning vestibular system (Harrington, 1969; Capps, Preciado, Paparella, et al, 1973; Coats, Herbert, & Atwood, 1976); whereas, Figure 5 illustrates the variables associated with the measurement of slow phase velocity (Jacobson & Newman, 1997).

Table 1. A detailed description of the caloric irrigation process from stimulation to vestibular nystagmus.

Stimulus	**Type**	**°C**	**Endolymph Changes**	**Electrical Response**	**Nystagmus**	**Vertigo**
Cool	Air	27.5	Shrinks	Hyperpolarization	-Slow deviation to stimulus ear (Slow phase) -Fast correcting saccade to opposite ear (Fast phase)	Spinning sensation toward opposite ear
	Water	30				
Warm	Air	45.5	Expands	Depolarization	-Fast correcting saccade to stimulus ear (Fast phase) -Slow deviation to opposite ear (Slow phase)	Spinning sensation toward stimulus ear
	Water	44				

The monitoring and measurement of vestibular nystagmus is commonly conducted via electro-oculography and includes the placement of three electrodes consisting of an active and reference electrode placed on the outer canthi of the eyes and the ground electrode placed on the forehead. The recordings of the corneo-retinal potentials of the eyes result in rightward and leftward eye movements normally displayed as upward and downward deflections from baseline, respectively (Carl, 1997). Measurement variables used to quantify caloric-induced nystagmus include duration, latency, amplitude, frequency, and, the most useful, velocity of the slow phase eye movements (Jacobson & Newman, 1997). Slow phase velocity (SPV), quantified as the slope or the number of degrees of eye movement deflection over a one-second period (°/sec) (Jacobson & Newman, 1997), demonstrates the greatest sensitivity to the presence of peripheral vestibular system asymmetries (Henriksson, 1956) and incorporates information about amplitude and duration. Clinically, most examiners quantify SPV as the average of 10 consecutive nystagmus beats at the peak of the caloric response, i.e., the fastest eye movements (Jacobson & Newman, 1997) usually occurring in the tasking segment (described below).

A timetable of the caloric test showing the specific sequence of activities in performing alternate binaural bithermal caloric irrigation is shown in Table 2 (Jacobson & Newman, 1997; Kileny, McCabe, & Ryu, 1980; Baloh & Honrubia, 1990). Caloric tests are usually administrated after necessary pre-test procedures, such as otoscopic evaluation, pre-test instructions, placement of electrodes or infrared goggles, and 10° saccadic calibration of eye movement (Jacobson & Newman, 1997). With the irrigator tip properly aimed at the tympanic membrane and the patient's vision eliminated via closure of the eyes or covered goggles, administration of the water or air stimulus occurs for 40 or 60 seconds with the onset of vestibular nystagmus at approximately 30 seconds of stimulation. At the close of irrigation, the examiner will gently remove the irrigator tip from the ear canal and begin a mental tasking exercise, while the patient remains deprived of visual input (Jacobson & Newman, 1997). These exercises are used to distract the patient from symptoms elicited by the caloric nystagmus and to prevent central suppression of the nystagmus for more accurate test findings (Jacobson & Newman, 1997). Simple conversation, commonly used to achieve these goals (Kileny et al, 1980), should be performed for approximately 40 seconds, while the examiner can subjectively note a peak in the SPV of the nystagmus, or a steeper slope, occurring at approximately 30 to 40 seconds into the tasking exercise (Jacobson & Newman, 1997). At this point, the clinician should instruct the patient to open his/her eyes to fixate his/her gaze on a target for approximately 20 seconds. Within two seconds, the clinician should examine a marked reduction in the SPV caloric response (typically 50%, Baloh & Honrubia, 1990), termed fixation suppression (Jacobson & Newman, 1997).

Table 2. A time-course description of the caloric tests.

IRRIGATION		**MENTAL TASKING EXERCISE**			**FIXATION**		**TOTAL (sec)**
Time (sec)	**Nystagmus Onset (sec)**	**Time (sec)**	**Task**	**Peak Time (sec)**	**Begin**	**Length (sec)**	
40 (water) 60 (air)	~30	~40-60	Simple conversation	~30-40	Peak SPV	20	100-140

Because alternate bithermal binaural caloric irrigation is designed to determine asymmetries between the horizontal semi-circular canals of the vestibular labyrinths, it is obvious that unilateral and bilateral vestibular disorders will manifest with different caloric responses (Shepard & Telian, 1994). A unilateral peripheral vestibular patient will reveal a weakness of one ear. The affected ear (Shepard & Telian, 1994) will reveal responses such as reduced SPVs during cool and warm irrigation of the affected ear, as indicated by a mathematical calculation (Appendix E) of a caloric weakness of ≥25% (Shepard & Telian, 1994). Results from a bilateral peripheral vestibular patient, however, will reveal weak or absent responses from both ears (Shepard & Telian, 1994), as indicated by SPVs less than 11^{o}/sec during warm calorics and 6^{o}/sec during cool calorics (Barber & Stockwell, 1980). Although caloric testing is of great importance, because physiologic and diagnostic information is given for each ear (Shepard & Telian, 1994), two important limitations of caloric testing are that regardless of its ability to lateralize a peripheral lesion (Shepard & Telian, 1994): (1) only physiologic function of the horizontal canals are analyzed -- deficits existing in the vertical canals or otoliths are not recognized (Shepard & Telian, 1994); and (2) administering calorics without rotational or head shaking tests may lead to an incorrect diagnostic inference about the broad frequency range of natural head (or head and body) movements (0.01 – 8 Hz) since caloric stimulation is only analogous to a head rotation of 0.003 Hz (Hamid et al, 1987; Cohen & Gavia, 1998; Fox & Stockwell, 1978; Tomlinson, Saunders, & Schwartz, 1980).

Clearly, multiple tests for clinical diagnosis and classification of vestibular disorders can provide the clinician with insight to the patient’s disorder. These results help the clinician determine whether further testing is warranted or identify the care suitable for the condition. In many cases care involves alleviating the symptoms during recovery, which can occur with the passage of time. There are a significant number of cases in which recovery does not occur naturally and successful care for some of these people is an intervention called vestibular rehabilitation.

Vestibular Rehabilitation

Spontaneous recovery, or central compensation, of the symptoms of a vestibular disorder should theoretically occur within ninety days of the onset of the disorder (Gans, 1999). However, too often, particularly in those with sudden-onset vestibular diseases, patients never experience, and thus do not benefit from spontaneous central compensation (Gans, 1999). Unless the patient suffers from a fluctuating peripheral vestibular disorder, such as Meniere’s disease, spontaneous recovery may not occur. Therefore, vestibular rehabilitation exercises are thought to be important in the management of vestibular patients (Nashner, 1997; Gans, 1999; Gans 2001).

According to the American Occupational Therapy Association (2000), “vestibular rehabilitation is the use of activities and exercises to treat vertigo, balance problems, functional limitations, and disability caused by the vestibular system”. While vestibular rehabilitation does not regenerate or directly treat the vestibular labyrinths, it encourages the CNS to adapt to the conflicting information ascending from the vestibular system (Gans, 1999; Gans 2001). Preferably, vestibular rehabilitation is performed on those patients who are stabilized, or beyond the acute phase of the disorder, with no remaining symptoms of nausea, vomiting, and severe vertigo, which makes the rehabilitative process more comfortable for the patient from the beginning (Gans, 1999; Gans, 2001). First developed and described by Cawthorne (1944) and Cooksey (1945), the original vestibular rehabilitation programs included repetitive and graded exercises to improve tolerance of various head movements. The Cawthorne-Cooksey vestibular rehabilitation exercises require the patient to gradually increase their eye and/or head movement throughout the exercise program. Present day accepted protocols have been modified and are designed to improve gaze and postural stability via increased head movement and facilitation of visual and somatosensory cues of balance. The new design of exercises emphasizes head and/or body movement over the “old” eye and head movement only exercises (Herdman, 1997b). See Appendix D for 10 clinically acceptable vestibular rehabilitation exercises (Gans, 2001).

Although the original exercises provided by Cawthorne (1944) and Cooksey (1945) for vestibular patients are utilized and well-respected by many rehabilitative practitioners (Gans, 1999; Gans, 2001), results of a fairly recent study indicate that patients rehabilitated with these exercises do not always show significant improvements in postural control and VOR gain (Szturm et al, 1994), two of the rehabilitation goals. Current supporters of vestibular rehabilitation suggest that the rehabilitation methodology should be altered to the individual, treating the particular dysfunction of each patient

(Gans, 1999; Gans, 2001). Gans (1999; 2001) described two diagnosis-based strategies which are suggested for rehabilitation: (1) adaptation exercises, which are designed to enhance VOR function and ameliorate symptoms caused by an asymmetry in the vestibular system, and (2) substitution exercises, which are designed to enhance postural stability and equilibrium by encouraging alternative compensation of the remaining sensory systems, vision and proprioception, on which the patient must rely to maintain balance. Adaptation exercises, which are typically used with unilateral peripheral vestibular patients due to the remaining functional vestibular apparatus, consist of task-oriented repetitive eye-head movements. For example, holding a playing card in each hand in front of one's face at arm's length and rapidly repositioning the eyes from one card to the next (Gans, 1999; Gans, 2001). This is thought to encourage adaptation where the system relies on accurate inputs from one strengthened healthy labyrinth, while "ignoring" weak signals from the affected side. On the other hand, substitution exercises, which are typically used with bilateral peripheral patients, consist of repetitive eye-head movements during ambulation or other whole body movement tasks. An example of walking down a hallway while turning one's head side to side with eyes open mimics the task of walking down a grocery store aisle looking for a particular brand of cereal (Gans, 1999; Gans, 2001). These substitution exercises are designed to encourage use of vision and proprioceptive inputs for unreliable signals from the damaged vestibular system. However, for unilateral patients, enhancing recovery of VOR gain is the most effective rehabilitation strategy for increasing gaze and postural stabilization since substitution exercises alone may cause balance difficulties when visual cues are removed (Herdman, 1997a, b) or visual or proprioceptive cues are degraded. In addition, including more functional and meaningful tasks into the vestibular rehabilitation program, such as playing Frisbee or catch, for the repetitive head movements by Cawthorne (1944) and Cooksey (1945) may increase patient compliance with participation in the program (Cohen et al, 1995). See Appendix D for more detailed descriptions and depictions of some examples of vestibular rehabilitation exercises.

Assessment of Success in Vestibular Rehabilitation

The success of vestibular rehabilitation has been assessed by establishing a pre-rehabilitation level of physiologic function, as determined by the original diagnostic evaluations using CDP, SHA, and caloric tests (Shepard & Telian, 1994), and a pre-rehab level of daily life function, as measured by levels of independence on two qualitative functional scales, the Vestibular Disorders of Activities of Daily Living (VADL, Appendix C) and the Dizziness Handicap Inventory (DHI, Appendix C) (Cohen & Kimball, 2000; Jacobson & Newman, 1990). To establish progress and improvements of overall balance function and daily life function, these tests have also been given at the midpoint of the treatment course and after the completion of rehab (Cohen et al, 1995; Cohen & Kimball, 2000; Cohen et al, 2000). The difference in pre- and post-test treatment scores of the CDP, SHA, and caloric tests and qualitative functional scales determine the success of vestibular rehabilitation. Patient reports on the frequency of vertigo with a description of when it occurs help to determine what actions may provoke it and to guide vestibular rehabilitation (Cohen et al, 1995; Cohen & Kimball, 2000; Cohen et al, 2000).

Accounting for age of the patient is also important when assessing vestibular rehabilitation. Unfortunately, with the normal aging process, regardless of the presence or absence of a vestibular pathology, there is a decline in the visual (Sekuler et al, 1980), proprioceptive (Skinner et al, 1988), and vestibular (Linthicum, 1989) systems. Because these normal aging declines accompany declines in balance abilities (Sekuler et al, 1980; Skinner et al, 1988), one can hypothesize that central compensation during vestibular rehabilitation of an elderly patient may be different than that of a younger vestibular patient (Cohen et al, 2000). Therefore, it is reasonable to postulate that elderly patients with a vestibular impairment may have more difficulty in environmental situations in which the visual input or support surfaces are compromised or manipulated as compared to their normal older peers or the young vestibular patient. Undoubtedly, proper assessment of vestibular rehabilitation needs to incorporate the aging effect (Cohen, 1994; Shepard & Telian, 1994; Cohen et al, 2002).

Overall, the results of the vestibular rehab assessments provide evidence that improvements can occur in standing posture (e.g. author), VOR function (Szturm et al, 1994), and functional skills (Cohen, 1992; Cohen, 1994; Cohen et al, 1995). Although these improvements may happen simultaneously, they are summarized independently in the next three sections.

Improvements in Diagnostic Assessments

Postural Control. Computerized dynamic posturography (CDP) is known to effectively assess postural control and has shown to be reliable in documenting improvement of postural control following vestibular rehabilitation (Black, 2001). The sensory organization tests (SOT) of the CDP are reported to measure the relative contribution of each of the three sensory systems – proprioception, vision, and vestibular – to the overall balance system (Black, 2001). In a previous study on the comparison of postural control of patients (Group A) who were trained with the Cawthorne (1944)-Cooksey (1945) exercises to patients who were trained with more modern vestibular rehab (including more visual fixation and changes in the support surface beneath the patients, Group B), Group B showed significant improvement in postural balance on the CDP while those in Group A showed no improvement in postural balance (Szturm et al, 1994). In addition, Cohen and colleagues compared the pre- and post-rehabilitation scores of postural control on the Computerized Test of Sensory Integrated Balance (CTSIB), a test very similar to the CDP (Cohen et al, 1995). While no treatment effects were noted in the subjects with peripheral vestibular dysfunction in conditions SOT1-SOT5, significant improvement in anterior-posterior sway were demonstrated on SOT6 (Cohen et al, 1995), which imposes the greatest challenge on the vestibular system (Black, 2001).

Vestibulo-Ocular Reflex Function. While CDP has consistently been a strong indicator of treatment efficacy of postural control improvement in vestibular rehabilitation, there is still much controversy in improvements in VOR gain, especially when measured via low-frequency SHA in darkness. It seems likely that the controversy stems from patient differences because SHA at a low frequency in darkness is known to effectively assess the VOR (Wolfe, Engelken, & Kos, 1978; Cohen et al, 2002). The failure to find improvement in VOR function should not be surprising, at least in the patients with bilateral deficits (Shepard & Telian, 1994). Remember vestibular rehabilitation is not used to repair and recover labyrinthine function in these patients (Cohen et al, 1995), thus VOR functional improvements should not be expected in those with bilateral deficits.

On the other hand, as mentioned previously, Gans (1999; 2001) clearly stated the adaptation strategy for vestibular exercises is specifically designed to enhance an abnormal VOR in the patient with a unilateral deficit. If adaptation exercises are used to rehabilitate unilateral patients, there should be an improvement in the VOR. In fact, VOR improvements were found in the experimental treatment group in a comparative study of the Cawthorne-Cooksey exercises and the more modern vestibular rehab protocol, which implements more visual fixation and changes in the support surface into the treatment program (Szturm et al, 1994). The latter group not only showed significant improvement in postural balance on the CDP but also an increase in VOR gain on the affected side during SHA in darkness, while those in the former group showed no improvement in postural balance or VOR gain (Szturm et al, 1994**)**. The authors' results clearly demonstrated that vestibular rehabilitation exercises utilizing more adaptation protocols compared to the Cawthorne-Cooksey exercises were more beneficial to unilateral vestibular disorder patients. Furthermore, animal studies on vestibular nerve section indicate that improvement of VOR gain in cats and monkeys does not begin until free or unrestricted head and/or body movements and vision are allowed (Courjou, Jeannerod, Ossuzio, et al, 1977; Fetter & Zee, 1988; Lacour, Roll, & Appaix, 1976). Although vestibular patients have VOR functional improvements in SHA tests it is not clear whether the recovery of VOR gain in patients occurs in more physiologic or functional head movements i.e., a quick head rotation (Halmagyi, Curthoys, Cremer, et al, 1990). Evaluating the eye movement control strategies (such as the VOR) of normal subjects, pre-rehab vestibular patients, and post-rehab vestibular patients during vestibular rehab exercises, could be advantageous in the future of vestibular research and the advancement of vestibular rehabilitation for the same reasons given for identifying kinematic strategies of body movements.

Improvements in Daily Life Function

Although CDP, SHA, and calorics are regularly referred to as tests of balance and/or vestibular function, they are, in fact, diagnostic assessments, which give insight to the physiologic function of the three sensory systems of balance (Shepard & Telian, 1994; Cohen, 1994). Results of these tests that are important for proper vestibular system assessment, do not reveal information regarding the impact of the vestibular disorder on daily life function (Cohen, 1992). To date, few studies have analyzed impairment of daily life function in patients with vestibular disorders (Cohen et al, 2000). In fact, few qualitative functional scales specific to vestibular disorders exist. Although qualitative in nature, the Vestibular Disorders Activities of Daily Living scale (VADL) and the Dizziness Handicap Inventory (DHI) have been shown to accurately evaluate functional problems of vestibular patients and are considered necessary additions to the physiologic diagnostic battery of clinical balance tests (Jacobson & Newman, 1990; Cohen et al, 2000; Cohen & Kimball, 2000). This need may be because they are the only reliable means currently used to assess functional behavior in these patients. The DHI, a 25-item 3-point questionnaire, assesses self-care skills, psychosocial behaviors, and physical activity. Although tested as reliable (Jacobson & Newman, 1990; Jacobson, Newman, & Hunter, 1991), some concern has been raised because of its broad nature and three-point Likert scale limit (Jacobson & Newman, 1990). The VADL, on the other hand, is a 28-item 10-point questionnaire, which assesses functional, ambulation, and instrumental (social activity) skills. Although it is relatively new with limited research to determine its validity and reliability (Cohen & Kimball, 2000; Cohen et al, 2000), the VADL directs assessment specifically related to vestibular system function and independence.

Regardless of their limitations, qualitative functional scales for vestibular disorders have consistently shown that chronic vestibular patients have had an extreme impairment in skills necessary for daily life function before undergoing vestibular rehabilitation therapy (Cohen & Kimball, 2000; Cohen et al, 2000) with a significant improvement post therapy (Cohen, 1992; Cohen et al, 1995). In fact, only a few studies have identified the functional deficits exhibited in these patients. In Cohen's study (1992) of functional disability of vestibular patients, subjects completed a four-page survey, the precursor to the VADL, on 41 activities of daily living (ADL) tasks and were asked to rank their level of performance in terms of independence on each task. The scale ranged from 0, total independence, to 5, total dependence. The subjects ranked their degree of independence on each task in terms of how s/he felt before the onset of the vestibular disorder, while in the midst of the disorder but pre-rehabilitation, and post-rehabilitation. Cohen (1992) found that major functional deficits in the subjects' ADLs during the disorder but pre-rehab included cleaning, gardening, rolling over in bed, lying down, getting out of bed, standing up, driving, transferring out of a car, bathing, climbing stairs, and walking whether on even surfaces, uneven surfaces, or long distances. Furthermore, Cohen (1992) reported that functional ability as indicated by ADL scales seems to be more important regarding the patient's functional status and degree of independence rather than the level of a caloric imbalance. While reliability on this particular test, the precursor to the VADL was not reported (Cohen, 1992), the VADL has been demonstrated to have high internal consistency ($r \geq .087$), good face validity, and high test-retest reliability ($r \geq 0.87$) (Cohen & Kimball, 2000).

Currently, the qualitative functional assessment scales are the only published means to gain information about a patient's functional status and degree of independence (Cohen, 1992). In addition, the scales have been tested reliable and give insight to the level of independence and function pre-, during, and post-rehab (Cohen 1992; Cohen et al, 1995). Johansson and colleagues (2001) also administered vestibular rehabilitation to a variety of peripheral vestibular patients in conjunction with cognitive behavioral therapy. Patients showed a significant improvement on all three subscales of the DHI - physical, emotional, and functional. In other studies, subjects with a variety of peripheral vestibular pathologies demonstrated a significant improvement in the ADLs on the VADL including bathing, upper extremity dressing, transfers, ambulation, driving, and home managements tasks and continued to maintain these improvements for at least three months post-rehabilitation (Cohen et al, 1994; Cohen, 1995).

Because the VADL shows much potential with a more thorough evaluation of function than the DHI (Cohen & Kimball, 2000; Cohen et al, 2000), it should be researched repeatedly to meet the requirements of an accepted instrument of the American Psychological Association (1985). To further validate the VADL, it has been suggested that future research studies include some aspect of the following: test-retest reliability over a long time period, comparisons to other ADL scales, and comparisons to objective diagnostic tests of physiologic and daily life function (Cohen, 1992; Cohen et al, 2000; Cohen & Kimball, 2000).

In order to truly measure the physical status, independence, and daily life function of an individual, one must quantitatively assess his/her performance during activities of daily living (Cress, Buchner, Questad, Esselman, deLateur, & Schwatrz, 1996; Cohen & Kimball, 2000; Cohen et al, 2000). The popularity of tests of physical functional performance has recently increased due to research concerns that subjective reports of function may be insufficient about the impairment type, lack sensitivity to change (Fried et al, 1994), and/or negatively influenced by personality factors, past illness or disability, psychological needs, and the demands brought about by significant others needing care, attention, or performance (Cohen & Kimball, 2000). Therefore, qualitative evaluations, such as the DHI and VADL, are best used in conjunction with an evaluation of case history and an objective assessment of daily life function (Cohen & Kimball, 2000).

A valid test of quantitative physical function in older adults is the Continuous-Scale Physical Functional Performance (CS-PFP) (Cress et al, 1996). The test consists of fifteen daily tasks representing everyday activities necessary for independent living. Common activities, such as transferring laundry from an actually washer and dryer, are performed by the subjects. For a complete description of the tasks and the validity of the CS-PFP, refer to Cress and colleagues (1996) study (Also see the CS-PFP test dialog in Appendix C). Subjects are timed in each of the tasks representing five domains: upper body strength, lower body strength, upper body flexibility, balance and coordination, and endurance. Based on collected norms of independent to disabled older adults, an average time (score) of sixty minutes is required to complete the test (Cress et al, 1996). Performance assessment is reflected in individual domain scores (average time to complete tasks in a given functional domain) and as a total functional performance score. All in all, there exists strong evidence that physical function is a more important predictor for living status than age (Cress et al, 1996). In other words, strength, endurance, flexibility, and, finally, balance and coordination contribute to physical independence more than the age of the individual. Moreover, the CS-PFP is also deemed a useful and valid tool in assessing the progress of a patient undergoing a rehabilitation program (Cress et al, 1996).

In the field of vestibular rehabilitation, evidence of self-perceived improvement in independence and daily life function exists (Cohen, 1992; Cohen, 1994; Cohen & Downs, 1996; Cohen & Kimball, 2000; Cohen et al, 2000) while empirical evidence of functional improvement as a result of vestibular rehabilitation is sparse (Johansson et al, 2001). Furthermore, a self-administered scale, such as the VADL or DHI, has several confounding limitations (Brown et al, 1996; Cohen & Kimball, 2000; Cohen & Kimball, 2000). (See Appendix C for an example of self-perceived scales.) The need for future studies to determine if subjectively rated independence and physical function among vestibular patients is the same as objectively rated independence and physical function (Cohen & Kimball, 2000) are needed. Thus, the *first purpose* of this study was to assess the physical functional levels of vestibular disorder patients (pre-rehab) and young and older control subjects. Relationships between subjective and objective assessments of ADLs were also examined.

Improvements in Kinematic Performance

While the SOT of CDP, or similar assessments of postural control, are claimed to be a sufficient indicator of treatment effectiveness of vestibular rehabilitation for postural control during a static condition (Szturm et al, 1994; Black, 2001), relatively few studies have objective, quantitative support for its use in more common dynamic conditions of daily function such as walking. Some researchers have quantified kinematic movement differences in vestibular patients. In one study, kinematic analyses were used to determine that bilateral patients used a different coordination strategy in a step and reach task (Daghestani et al, 2000-). Although final reach positions and spatial positioning of the head were similar, patients were found to utilize an abnormal elbow extension, trunk rotation, and curvature of the hand path compared to control subjects (Daghestani et al, 2000). Furthermore, it has been reported that patients with unilateral and bilateral peripheral vestibular dysfunction demonstrate an ataxic gait pattern characterized by a widened base of support, frequent sidestepping, a tendency to drift during ambulation, and decreased trunk and head rotation (Herdman, 1997). This author proposes that gait ataxia helps to reduce the asymmetric vestibular signals brought about by increased head movements, thereby reducing the associated symptoms. Because these patients have no known history of experience with vestibular rehabilitation, it is reasonable to postulate that analyzing the kinematic strategies of vestibular patients and normal subjects during dynamic tasks, such as the actual rehab exercises, could aid in the future advancement of vestibular rehabilitation. Specifically, normal performance by non-rehabilitated patients during a certain exercise may indicate the need to eliminate it from the therapy regime. Therefore, the *second purpose* of the present study was to describe various movement kinematics used during performance of 10 vestibular rehabilitation exercises and to compare kinematic performance of body movements used by patients with chronic vestibulopathy and no history of vestibular rehabilitation, young control subjects with no neurological deficits, and age-matched control subjects.

Comparisons among kinematic variables while performing different VR exercises will help identify movement differences for subjects performing these specific tasks. Identifying links between these differences and perceived or actual ADL abilities will help make the movement difference more meaningful. Therefore, the relationship between the behavioral strategies used during the 10 rehabilitative exercises and physical functional level, according to each patient and control subjects' functional scores will be compared. Comparing the subjective and objective functional performance scores to kinematic variables obtained during VR exercise performances in normal subjects and non-rehabilitated vestibular patients should aid in the better understanding of, thus the advancement of vestibular rehabilitation. Therefore, the *final purpose* of the present study was to examine the relationship between the movement kinematics used during the 10 rehabilitative exercises and physical function.

Overall, the present study is designed to: (1) examine the existence of a correlative relationship between the total and subscale scores of the subjective scales, VADL and DHI, and the objective assessments, CS-PFP, across and within subject groups – normal young, normal old, and chronic vestibulopathic with no rehab; and (2) compare the physical function measures to the kinematic variables that contribute to movement kinematics used by the three subject groups. The immediate goal of this work is to identify vestibular rehab advances that would clearly benefit those with vestibular disorders. Ultimately, results of the proposed study may also explain falls in the elderly population due to vestibular system degradation, which is known to occur with age (Linthicum, 1989).

METHODOLOGY

Subjects

Thirty-four individuals served as subjects in this experiment. Subjects met certain qualifications to participate in the study. Qualifications were determined by group with the exceptions that all subjects must have met minimum requirements. All subjects were able to maintain an upright posture and walk at least 20 yards without assistance. Individuals with (a) a history or evidence of central nervous system dysfunction; (b) musculoskeletal deformity; (c) unstable angina; and (d) unstable diseases (e.g. uncontrolled diabetes mellitus, arthritis, coronary artery disease, etc.) were excluded from participation.

Subjects were categorized into one of three groups: a young healthy control group, an older healthy control group, and a patient group. Control groups consisted of 26 healthy subjects with no history of outer, middle, or inner ear pathologies, or neurological or balance disorders and were split into two groups based upon age: 13 young between the ages of 18 and 41 (Group Y) and 12 older adults 65 years and older (Group O). Although older adults are defined in the literature as persons 60 or 65 years and older, we chose the latter due to the fact that most patients with vestibular disorders are over the age of 65 years (Brocklehurst et al, 1978). The patient group (Group P) consisted of 9 patients 65 years or older diagnosed with a unilateral chronic vestibulopathy based on: (1) patient complaint of vertigo, imbalance, and/or motion-provoked dizziness; (2) unilateral caloric weakness and/or reduced VOR gain and/or vestibular after-nystagmus during high-frequency headshakes, (3) increased postural sway during the sensory organization performance (SOP) test, particularly the conditions five and six (see below for details), and (4) any symptoms of acute vertigo were stabilized and non-compensated. Refer to Table 3 for diagnostic qualifications of the patient group and the young and old control subjects.

Qualifications of Examiners

A certified and state-licensed audiologist with extensive clinical experience in vestibular assessment and rehabilitation performed examinations and administered the written instruments and training of the vestibular rehabilitation exercises to all subject groups. A licensed physical therapist that conducted the functional performance test (CS-PFP-10) had over three years of experience working with older patients.

Table 3. Subject classification criteria for each group.

REQUIREMENTS	GROUP Y	GROUP O	GROUP P
Hearing Sensitivity	No evidence of medical related ear pathology	No evidence of medical related ear pathology	No evidence of medical related ear pathology
Tympanograms	Type A	Type A	Type A
Otoscopic Exam	Unremarkable	Unremarkable	Unremarkable
Ear Health History	Unremarkable	Unremarkable	History of unilateral vestibular disorder and associated symptoms
Vertebral Artery & Cervicospinal	Negative results	Negative results	Negative results
Dix-Hallpike	Negative results	Negative results	Negative results
HFHS	Normal VOR gain (1.0) and/or no after-nystagmus	Normal VOR gain (1.0) and/or no after-nystagmus	Possible reduced VOR gain and/or after-nystagmus
SOP	No abnormal postural sway	No abnormal postural sway	Possible increased postural sway/fall on SOP 5 or 6
Calorics	Normal	Normal	Possible caloric weakness or directional preponderance (Appendix E)
Vestibular Rehabilitation	No history or experience	No history or experience	No history or experience

Experimental Protocol

The subjects were asked to report to the laboratory on three occasions no more than 1 week apart. In *Session I*, subjects were screened for health history and inner ear disorders. Qualification and classification status were determined by the completion of an audiological case history form (Appendix B) and audiological and vestibular assessments (see below). In *Session II*, the subjects were evaluated for balance and activities of daily life function utilizing subjective and objective functional assessments (see below and/or Appendix C). Evaluation procedures followed standard protocol for each test in sessions I and II. Note that young subjects did not participate in the objective functional assessment CS-

PFP-10, as it is not validated for young healthy adults. In *Session III*, the subjects first received instruction on how to perform the 10 specific vestibular rehabilitation exercises (Appendix D), and then perform each of the 10 exercises 10-20 times (see Appendix D for the prescribed number of trials of each exercise). Table 4 provides an outline of the assessments or tasks in each session, whereas the text that follows provides details of the instruments and experimental procedures.

Table 4. The assessments or tasks associated with each session.

SESSION I (1-1.5 hours)	**SESSION II (45 min-1 hour)**	**SESSION III (1-1.5 hours)**
Informed Consent Signed Audiologic Case History Otoscopic Examination Immittance Measures Pure Tone Air and Bone Audiometry Sensory Organization Performance (SOP) test Vestibulo-collic Screening (VEMP) Vertebral Artery Screening Cervicospinal Screening High Frequency Head Shake ENG: Oculomotor, Positional, and Caloric Tests (Appendix E)	VADL DHI CS-PFP10 (Appendix C)	Two to five practice trials of each VR exercise (Appendix D). Performance trials consisting of at least 10 repetitions each VR exercise (in each direction or sub-condition, where appropriate). Breaks taken as needed

Instruments

Health Screening Instrument. An audiological case history was used to provide the examiner with a qualitative report of the subjects' auditory and vestibular history (see Appendix B) (Ginsberg & White, 1994). This was required to determine subject qualification in the study and classification into specific subgroups.

<u>Case History.</u> In addition to identifying subjects at risk for various diseases that may result in adverse responses to physical activity, this instrument provided the examiner with insight into the subject's perception of their auditory and vestibular health as well as major medical conditions (see Appendix B) (Ginsberg & White, 1994).

Audiological and Vestibular Assessments. An otoscopic examination (Ginsberg & White, 1994) was performed by a licensed audiologist. Measurements included: immittance measures (Block &

Wiley, 1994) using a Maico 630 impedance bridge; pure tone audiometric evaluation (ANSI S3.6-1989) using a Maico 40 air and bone audiometer; vestibulo-collic screening (Al-Sebeih & Zeitouni, 2002) using Biologic Auditory Evoked Potentials equipment and software; vertebral artery screening (Grad & Baloh, 1989), cervicospinal screening (Norre & Stevens, 1987), high frequency head shakes (Kamei, 1988), modified Dix-Hallpike maneuver (Baloh, Honrubia, & Jacobson, 1987), sensory organization performance (SOP) test (Gans, 2001), and oculomotor, positional, and caloric subtests of electronystagmography (ENG) (Furman, 1997). An ICS NCA200 air caloric irrigator was used to induce the caloric nystagmus.

Otoscopic Examination. The purpose was to visually examine the subject's external auditory canal (external auditory meatus) and the quality of the tympanic membrane. A certified clinical audiologist ensured integrity of both structures (Ginsberg & White, 1994) to rule out outer and middle ear pathologies that could influence other test results.

Immittance Measures. The purpose was to measure the subject's physiologic function of his/her middle ear including ear canal volume, mobility of the tympanic membrane (ear drum), air pressure in the middle ear cavity (& Eustachian tube function), acoustic reflex threshold of the stapedial muscle and vestibulocochlear nerve function. For the purposes of our project, middle ear tests were important because (1) middle ear disease may give abnormal caloric responses while the inner ear functions normally and (2) sometimes subjects with middle ear disease have balance problems because of the difference in ear pressure, hearing, and fluid between ears (Block & Wiley, 1994).

Pure Tone Air and Bone Audiometry. The purpose was to obtain a subject's lowest level of hearing sensitivity (dB HL) across a wide range of frequencies (250-8000 Hz) to quantify inner health of the auditory system. The subject raised his/her hand when he/she heard the pure tone air and bone signal via earphones and a bone oscillator (ANSI S3.21-1997), respectively, while seated in a quiet room (ANSI S3.1-1991).

Sensory Organization Performance (SOP). The purpose was to assess the patient's ability to balance utilizing the three sensory systems (visual, proprioception, and vestibular) for postural control. The subject stood on either a hard floor surface or a foam cushion, with his/her eyes open or closed, and with his/her feet close together (one in front of the other) or far apart (about shoulder width) creating seven total conditions. For safety purposes, the subject had an examiner within arm's length and a safety harness for them to grab hold of in case of extremely increased sway. In the seven conditions, the isolation of each system was accomplished by altering the stability of the support surface and the visual input. A qualitative assessment was made for each condition, estimating the amount of sway (N-normal, S-sway, F-fall/step/assistance) or right or left rotation. The amount of sway in each condition was compared to the wide stance, eyes opened, hard surface condition within subjects and across subjects. Conditions, which caused imbalance requiring external support, were reported (Gans, 2001).

Vertebral Artery Screening. The purpose was to identify a possible existence of any problem with the blood supply from the vertebral artery, especially to the inner ear, to eliminate subjects at risk for stroke or other vascular related problems. Because the vertebral artery makes a 90^o angle before entering the inner ear, certain head positions/maneuvers could "kink" the vertebral artery in some people (because of anatomical differences) resulting in specific symptoms, one of which is dizziness. To perform this, the subject sat in a chair, leaned forward, extended his/her neck, rotated his/her head up and to one side, counted to 20 out loud, and then reported any symptoms present. Specific symptoms resulting in a positive screening and subject exclusion were diplopia, dysphagia, dizziness, and nausea (Gans, 2001; Grad & Baloh, 1989).

Cervicospinal Screening. The purpose was to identify the possible existence of a malformation/problem in the cervicospinal column, which could cause dizziness. The subject sat up straight in a chair, turned his/her head to one side, holding it for 20 seconds, and was asked to report any symptoms he/she might be feeling. Then, repeated on the other side. Specific symptoms resulting in a positive screening and subject exclusion were diplopia, dizziness, and nausea (Gans, 2001; Norre & Stevens, 1987).

High Frequency Head Shake. The purpose was to identify vestibular problems occurring at high frequencies (i.e. high frequency head movements or the perception that the head is moving at a high frequency after the head shake). Other tests of vestibular function only measure low frequency while natural head movements occur at higher frequencies. To perform this, the subject shook his/her head back and forth quickly for 20 seconds. The patient fixated on an object while the clinician examined his/her eyes looking for the presence of nystagmus and its direction. Many vestibular patients go undiagnosed because their disorder exists only with high frequency movement, which is often untested in many vestibular and balance clinics (Gans, 2001; Kamie, 1988).

Modified Dix-Hallpike Maneuver. The purpose was to identify the presence of Benign Paroxysmal Positional Vertigo (BPPV), or dislodged otoconia in the semi-circular canals, via positive results on the Dix-Hallpike maneuver. With the patient's head turned to one side and seated on an exam table, the examiner supported the subject's head, neck, and back while he/she laid supine with his/her head ultimately hanging off the table and turned to a 45^o angle to maximally stimulate the posterior canals. This was repeated on the other side. Specific symptoms resulting in a positive Hallpike and, therefore, subject exclusion were a burst of rotary-torsional nystgamus and reported vertigo (Baloh et al, 1987).

Ocuolomotor Tests. The overall purpose of the first three assessments of electronystagmography was to test motor control/function of the eyes. These tests are thought of as assessments of the central system related to the vestibular system in the field of audiology. Recordings were compared to aged-matched norms and when test performance was poor, the results indicate whether the origin of the problem was linked to the vestibular or neuromuscular systems. *Smooth Pursuit.* The subject tracked a slowly moving object. This is primarily an ipsilateral pathway through the brain. Results were displayed as a sinusoid and were measured in terms of gain (absolute peak eye velocity/absolute peak target velocity) and phase (the distance in degrees between peak eye and peak target velocity). *Saccades.* The subject rapidly repositioned his/her gaze to a moving target (target to target). This is primarily a contralateral pathway through the brain. Results were displayed as square waves and were measured in terms of accuracy, latency, and velocity. *Optokinetics.* A series of continuous moving targets appear on a light bar, screen, or wall. The subject simply looked in the midst of the targets. The optokinetic "reflex" allows the subject to track the object in its "slow" pathway and then rapidly reposition to a new target. Results were displayed like nystagmus beats and were measured in terms of gain and symmetry (left positive gain/right positive gain). *Gaze.* While all other oculomotor tests are visually driven gaze testing is not. The subject simply focused on a target for about 20-30 seconds. The presence of nystagmus was evidence for a conflict between the visual and vestibular systems (Hain, 1997). Any eye movement test with abnormal findings resulted in subject exclusion.

Positional Tests. While placing the human body in different positions, the vestibular system may react with signs of nystagmus. One way to distinguish between a central and peripheral vestibular disorder is through measuring fixation suppression. Therefore, the examiner had the subject lie flat on the exam table (supine), with his/her head to the right, or with his/her head to the left. The subject was then instructed to close his/her eyes. The subject was then told to open his/her eyes and fixate on a target. Many results can be obtained: no nystagmus, nystagmus with eyes closed but reduced with eyes open (fixation suppression), nystagmus with eyes closed and open (no fixation suppression), and nystagmus inappropriately changing direction throughout the testing (Brandt, 1997). Up or down beat nystagmus would result in subject exclusion.

Caloric Irrigation. Four caloric irrigations with cool and warm air were performed in each ear to measure the physiologic function of the horizontal semi-circular canals (cool air, 27.5ºC and warm, 45.5ºC, Coats et al, 1976). While using EOG, standard clinical protocol, and with the subject's head at a

30^o angle (to make align the horizontal canal parallel to the gravitational vector, Jacobson & Newman, 1997) while lying on an exam table, the cool or warm air was aimed at the tympanic membrane for 60 seconds. The cool or warm air expanded or shrank, respectively, the fluid inside the horizontal canal. This caused an inhibitory or excitatory response resulting in a VOR response, vertigo, and nystagmus toward the excited ear. Results were measured in terms of slow-phase velocity (SPV) of the nystagmus beats, symmetry between the ears, and fixation suppression (Jacobson & Newman, 1997).

Functional Measures. The Vestibular Disorders Activities of Daily Living (VADL) (Cohen & Kimball, 2000) and the Dizziness Handicap Inventory (DHI) (Jacobson & Newman, 1990) were used to assess the subjects' subjective inner ear health and daily life function. See Appendix C to view the VADL and DHI. The CS-PFP (Cress et al, 1996) was used to objectively assess the subjects' daily life function. See Appendix C to view the CS-PFP test dialog.

Dizziness Handicap Inventory (DHI). This qualitative assessment was initially designed for a specific group of patients with vestibular disorders: Meniere's disease. Although this questionnaire has been used over the years in clinics and in research, its reliability has been questioned due to its broad nature. It assesses self-care skills with only a 3-point scale. Having subjects complete both assessments (the VADL and DHI) should provide greater insight into vestibular health (Appendix C) (Jacobson & Newman, 1990).

Vestibular Disorders Activities of Daily Living (VADL). This new qualitative assessment was specifically designed for vestibular patients. It was designed to include very specific situations that only vestibular patients may have difficulty with and is broken into three main categories: functional, ambulation, and instrumental (social) skills (Appendix C) (Cohen & Kimball, 2000).

Continuous Scale Physical Function Performance (CS-PFP-10) Test. A similar test battery (CS-PFP) was first validated in 1996 (Cress et al, 1996). It includes several tasks that require the subject to perform ADLs (e.g., carrying a pot from the sink to a stove, emptying a washer, walking a flight of stairs, sweeping a floor, etc.) in a standardized fashion. The tests are either time to completion scores, and/or weight carried, height reached, etc. More recently a short version of the test, the CS-PFP-10, yielded “valid, reliable and sensitive measurements” to be substituted for the CS-PFP (Cress, Petrella, Moore, & Schenkman, 2005). The test-retest reliability and inter-tester reliability, and observed intraclass correlation coefficients to be in the range of 0.87-0.95 (Fabre, Wood, Cherry, Su, Cress, King, deVeer, Ellis, & Jazwinski, 2009). See Appendix C for the CS-PFP-10 test dialog.

Vestibular Rehabilitation Exercises. The 34 subjects were trained to perform 10 vestibular rehabilitation exercises utilizing adaptation and substitution strategies to target unilateral and bilateral patients, respectively. However, the examiner, a certified licensed audiologist, instructed the subjects to perform “body movements”. The examiner did not disclose the information that the movements were vestibular exercises until after completion of the experiment. The exercises required use of a straight-back chair, a beach ball, a deck of cards, an index card with a written shopping list, a lamp, and three external targets at eye level. See Appendix D for detailed information about each exercise.

Experimental Procedure

Session I. The subjects reported to the laboratory 12 hours post-prandial and 48 hours post-CNS suppressant medication. The study was explained in detail to the subject, and informed consent was obtained prior to any of the following procedures. The subject answered questions regarding his or her health status and inner ear history (Appendix B) to insure that the inclusion/exclusion criteria and appropriate subject classification for the study were met. After the completion of the case history, a certified clinical audiologist examined the external auditory canal. Next, middle ear immittance was assessed with a clinical immittance bridge (Maico 630). Then the hearing sensitivity of the subject was assessed in a quiet room with appropriate ambient noise levels (ANSI S3.1-1991) and with pure tone air and bone conduction (Maico Audiometer 40). Then, the subject performed the appropriate static balance tasks on a hard and soft foam surface for the SOP, the functional assessment of postural control.

Following this, the subject required the placement of electrodes at the right and left outer canthi and the low forehead. These electrodes were used to examine eye movement during the vertebral artery screening, cervicospinal screening, high frequency head shake, modified Dix-Hallpike maneuver, oculomotor tests, positional tests, and calorics of the electronystagmography, which gave pertinent functional information about the vertebral artery, cervicospinal column, velocity storage of the peripheral vestibular system, the posterior semi-circular canals, the ocular muscles, and the peripheral and central vestibular systems. All measures were performed using standard audiological protocols and a description of each of the above-listed assessments was given previously (see Instruments).

Session II. The subjects reported to the laboratory 12 hours post-prandial and 48 hours post-CNS suppressant medication. The study procedure was re-explained in detail. The subject then completed the *VADL* and *DHI* and performed the functional tasks of the *CS-PFP-10.*

Session III. The subjects reported to the laboratory 12 hours post-prandial and 48 hours post-CNS suppressant medication. The study procedure for the session was re-explained in detail. The subject was instructed how to perform the 10 vestibular rehabilitation exercises: saccades; tracking; targets; horizontal head movements; head circles; focusing with head turns; ankle sways; circle sways; ball circles; and gait with head movement (Appendix D). These 10 exercises are commonly distributed by otolaryngologists and audiologists for at-home VR. The subject practiced each exercise for two to five cycles with guidance from the examiner. Next, the subject was equipped for data collection.

Eye and body movements were recorded during exercise performance. Electro-oculography (EOG) used for eye movement recordings required the placement of three electrodes on the subject's head: one on the forehead, and one on each side of the head in the area of the articulation of the temporal and sphenoid bones. Recordings represent the corneal-retinal potential, which changes with respect to the reference electrode during eye movements (horizontal in this case). EOG recordings were made at 1000 Hz using the *Biopac*. The *Biopac* digital recordings were digitized and stored with the companion

Acknowledge 3.7.2 software (Santa Barbara, CA) and simultaneously synchronized and recorded at 120 Hz with the kinematic data. Reflective markers were placed on the shoulder, elbow, wrist, hip, knee, ankle, and top of foot at the second tarsal-metatarsal joint bilaterally. Three reflective markers were also placed along the midsagittal plane of the head for three-dimensional recordings during exercise performances of all tasks but the Gait with Head Movements. These head markers were placed on the head via a Styrofoam helmet (295g) securely positioned with a chin strap to maintain proper stability of the helmet. The locations of the passive markers were recorded (120 Hz) with a three camera digital motion camera system (Qualisys Medical AB). Due to the limited recording area of this system, a Panasonic digital video recording camera (60 Hz) was used to assess dynamic gait.

After being equipped the subject practiced, then performed each exercise set at least ten times. All older subjects were wearing a gait belt and were closely monitored by the examiner to prevent falls. The order of these exercises was randomized with Gait with Head Movement always performed at the beginning or end of the exercise set. Table 5 gives a brief description of each exercise, and the parameters of interest, including descriptions of these parameters. Breaks were given between exercises and at the subject's request. For more detailed information on the specific exercises, see Appendix D.

Data Analyses

Analyses required subjective and objective observations to provide a clear understanding of the expected movement differences among groups. Qualitative analyses, such as viewing the videotapes of task performance or inspecting the raw data in graphical displays, were performed to help explain the quantified findings.

Data Reduction

Prior to determining parameters, position data were reduced so that artifacts were removed and filtered so that errors associated with data collection were minimized, while actual movement data were maximized. Position data from the body markers were filtered at 6 Hz, a common cut-off frequency used

Table 5. A description of the 10 vestibular rehabilitation exercises and measurement parameters.

VR EXERCISE	DESCRIPTION	VARIABLE(S)
Saccades	Quick eye movements between two cards - horizontal, vertical, diagonal. (monitor horizontal only)	Pitch/yaw/roll head angle excursion. Temporal aspects.
Tracking	A card is moved back/forth (horizontal, vertical, diagonal), while maintaining fixation. (monitor horizontal only)	Pitch/yaw/roll head angle excursion. Temporal aspects.
Targets	The head is moved to focus on 3 eye-level targets – with and without stopping the head. (monitor with stopping only)	Nystagmus. Pitch/yaw/roll head angle excursion. Temporal aspects.
Horizontal Head Movements	Quick horizontal head turns – center, right, left, center…	Nystagmus. Pitch/yaw/roll head angle excursion. Temporal aspects.
Head Circles	The head is moved in a circular motion - eyes open/closed.	Nystagmus. Pitch/yaw/roll head angle excursion. Temporal aspects
Focus, Head Turns	Head rotations during eye-level fixations.	Nystagmus. Pitch/yaw/roll head angle excursion. Temporal aspects.
Ankle Sway	Weight is shifted back/forth & side-to-side at the ankles – focus is on an eye-level target.	Nystagmus. Hip & ankle angle excursions. Pitch/yaw/roll head angle excursion. Temporal aspects. Wrist & ankle variability. CoM distance.
Circle Sway	Weight is shifted in a circular motion at ankles.	Nystagmus. Hip & ankle angle excursions. Pitch/yaw/roll head angle excursion. Temporal aspects. Wrist & ankle variability. CoM distance.
Ball Circles	Eyes fixate on a ball that is circled above the head down to the floor and back	Nystagmus. Hip & ankle angle excursions. Pitch/yaw/roll head angle excursion. Temporal aspects. Wrist & ankle variability. CoM distance.
Gait with Head Movement	Walking and turning the head to each side every three steps.	Step path.

Temporal aspects—the time to complete each cycle & variability (s.d.) across five cycles.

Pitch/yaw/roll/hip/ankle angle excursion—the pitch/yaw/roll head or hip/ankle angular distance (maximum – minimum angle) for each cycle & its variability (s.d.) across five cycles.

Nystagmus—is nystagmus present during or post movement as identified by visual inspection of the EOG recording. Used for descriptive purposes only.

Identify balance loss—Assistance used as stated by examiner. Visually inspect full body recordings for evidence of large arm or leg movements. Used for descriptive purposes only.

Wrist and ankle variability—variability of left to right wrist or ankle distance to identify loss of balance via flailing arms and/or taking a step, respectively.

CoM distance—length of CoM displacement for each cycle & its variability (s.d.) across five cycles

Step path—average gait time in seconds (each trial of gait with head movement defined by time on digital video recording from beginning of first step to end of last step); average number of steps (sum of steps in each trial during each trial as defined above); average cadence in seconds (number of steps/total time to complete them) & veering left or right (used for descriptive purposes only) as seen on the videotape.

in gait analyses (Winter, 1990), a similar cyclic speed to those used in the faster exercises.The synchronized position data of the top head marker and the right wrist were differentiated with respect to time to determine the tangential velocity of each marker. Position and velocity profiles were plotted across time, visually inspected, and each cycle was marked for the frame of movement onset and termination. Because the major movement for the saccade exercise is eye movement, EOG position data were used to determine the frames for each of the saccade exercise cycles. Only five cycles (cycles 4-8) were used to identify parameters listed below.

Before calculating the appropriate parameters for results, several kinematic variables were determined from the movement recordings during the performance of the vestibular rehabilitation exercises. The time of each cycle was determined by taking the difference between start and end frames and dividing by the 120 Hz collection rate. Concurrent EOG data were viewed to determine the presence or absence of nystagmus within each cycle. Estimation of the center of mass (CoM) location was determined by taking the average locations of the left and right hip and shoulder markers and calculating the location 62.6% of the distance between mean locations relative to the mean shoulder location (Winter, 1990). Hip angle was calculated as the angle formed by the left shoulder, hip, and knee markers, while ankle angle was calculated as the angle formed by the left knee, ankle, and top of foot markers. Left markers were used, as these markers were more visible thus recorded more often than those on the right side of the body. The three markers on the head were used to calculate pitch, yaw, and roll angles of the head. Pitch angle, associated with nodding the head “yes”, was determined as the angle between line connecting mid and front head markers and the horizontal. Yaw angle, associated with a “no” nod, was determined as projection of the mid and front head marker line into the horizontal plane.

Roll angle, corresponding to an angle in the frontal plane formed by moving the head from the left ear at the left shoulder to the right ear toward the right shoulder, was calculated as the angle formed by the cross product of mid-front marker and mid-top marker lines and the horizontal.

Parameters

The parameters chosen depended on the movement/exercise being performed and included temporal aspects, pitch/yaw/roll head and hip/ankle angle excursions, nystagmus, identifying balance loss, and step path. The parameters of interest for each exercise are listed in Table 5 and described in the associated legend.

Statistical Analyses

Quantitative Analyses. A Pearson-product Moment correlation was used to help validate responses between subjective scales: VADL to the DHI (session II). A Pearson-product Moment correlation was also used to describe the association of qualitative (VADL & DHI) and quantitative (CS-PFP-10) physical function, within and across groups, to assess the existence of a relationship between the subjective and objective functional performance of ADLs in session II. In order to identify movement control strategies (session III), a linear regression controlling for age and patient group was used to quantify group differences in movement parameters and temporal aspects associated with the given task (see measurement parameters listed in Table 5). If a significant effect of age was present, then a second linear regression was used to quantify an age effect within the patients. Finally, in order to determine whether the kinematic performance in VR exercises was linked to subjective and objective physical function, known to improve with VR, kinematic parameters were compared to total and subscale VADL, DHI, and CS-PFP-10 scores using a Pearson-product Moment Correlation. While a Spearman correlation may be more appropriate for analysis of categorical data, such as those obtained in the VADL and DHI, the subscale and total scores of the perceived and actual functional assessments are summary scores, and therefore, deemed in the continuous dimension. A one-way ANOVA with post hoc testing (Tukey HSD) was used to further identify group differences in subjective and objective functional performance as well as the parameter of interest. For all statistical analyses, alpha was set a-priori to 0.05.

Qualitative Analyses. Graphical displays of the raw data of the above parameters were subjectively reviewed to note obvious trends and/or differences across subject groups. These trends/differences may also have been identified in videotaped performances of the exercises.

RESULTS

The results of this study are presented in three major subsections on data from young healthy controls (age = 23.64 ± 3.38 years, Group Y), older healthy controls (age = 80.67 ± 4.01 years, Group O), and patients with unilateral vestibular hypofunction (age = 72.11 ± 16.30 years, Group P). The focus of the first section is to compare measures of actual and perceived physical function across groups to offer insight to functional alterations that occur due to vestibular deficits and those of normal aging. Associations between actual and perceived measures within groups also provided insights to these links for each group. The focus of the second section was to describe and compare the movement performance during VR exercises across groups to offer insight to exercise kinematics differences among groups. In the third section the focus was to compare kinematic and functional measures to see if certain kinematic measures could be used to explain the functional outcomes. Second and third sections concentrate on each of the ten exercises but are presented as subdivisions for the eye exercises, head and eye exercises, and whole body exercises to help with interpretation. Before examining functional measures across and within groups, individual data of the perceived function (VADL and DHI) and actual function (CS-PFP-10) give insight to the patient (Table 6) and older adult (Table 7) populations used. Individual data for the young healthy adults are not presented as these subjects reported having no dependence or handicap as determined by the VADL and DHI, respectively.

Functional Measures

The first purpose of the present study was to examine the existence of a correlative relationship between total or subscale scores for the different functional measures (subjective scales: VADL and DHI; and objective assessment: CS-PFP-10) across all groups and within groups O and P. Remember that young control subjects did not perform the CS-PFP-10, as this test is not deemed appropriate and has not been tested as valid or reliable for young, healthy individuals. Due to scheduling conflicts, one older control subject also did not participate in the CS-PFP-10. Mean VADL, DHI, and CS-PFP-10 subscale and total scores were averaged for each group and are listed in Table 8. Note that all young

Table 6. Diagnostic characteristics of each patient with a unilateral vestibular disorder.

Group P		**Patients with Unilateral Vestibular Disorder**								
		P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**
Age		91	74	76	86	68	56	63	58	77
Gender		F	F	F	F	M	F	F	F	F
Dizziness/ Imbalance Symptoms		Veers left	Falls right, veers right, nausea	Veers right	Vertigo, falls right, veers right and left	Vertigo, falls back, veers left	Motion-provoked, falls forward	Motion-provoked	Motion-provoked, nausea	Motion-provoked, falls right, veers right
Lesion Side		Right	Left	Left	Right	Right	Right	Right	Right	Left
Abnormal Test Results		LB on HFHS	Right CW	RB on HFHS, Left CW	RB on HFHS, Left CW	LB on HFHS	Right CW	LB on HFHS	Left CW	LB on HFHS, Right CW
VADL	**AMB**	36	35	48	56	25	24	13	37	34
	FXAL	37	33	46	46	38	24	32	83	81
	INSTR	28	23	33	19	30	20	29	28	14
	TOT	**101**	**91**	**118**	**111**	**73**	68	60	**92**	**81**
DHI	**PHYS**	16	18	18	14	6	14	14	17	16
	FXAL	26	18	22	28	12	16	0	13	13
	EMOT	24	22	14	14	4	6	2	13	10
	TOT	**66**	**58**	**54**	**56**	22	**36**	16	**43**	**39**
CS-PFP-10	**UPSTR**	14.73	50.84	43.69	4.13	31.31	33.18	58.46	41.03	50.44
	UPFLEX	50.5	62	60.63	53.95	44.65	82.93	39.59	76.48	81.34
	LOSTR	33.08	40.38	52.62	4.51	22.56	34.38	62.38	47.1	62.39
	BC	40.07	45.1	46.24	4.1	16.47	42.59	55.72	38.88	56.54
	END	44.79	48.6	57.72	8.86	23.82	50.37	66.96	54.16	67.44
	TOT	**37.19**	**47.15**	**51.75**	**9.31**	**24.66**	**45.19**	60.28	**49.06**	62.02

VADL Total scores greater than 70 = high dependence. DHI Total scores greater than 30 = moderate handicap and scores greater than 60 = high handicap. CS-PFP-10 Total scores less than 47 indicate low physical function and scores between 47 and 56 = moderate function. The total scores achieving moderate to high dependence, moderate to high handicap, and low to moderate physical function are in bold. Abbreviations for the above table are the following: F, female; M, male; LB, left-beating nystagmus; RB, right-beating nystagmus; HFHS, high frequency headshake; CW, caloric weakness; VADL, Vestibular Disorder Activities of Daily Living; AMB, Ambulation; FXAL, Functional; INSTR, Instrumental; TOT, Total; DHI, Dizziness Handicap Inventory; PHYS, Physical; FXAL, Functional; EMOT, Emotional; TOT, Total; CS-PFP-10, Continuous Scale of Physical Functional Performance; UPSTR, Upper Body Strength; UPFLEX, Upper Body Flexibility; LOSTR, Lower Body Strength; BC, Balance and Coordination; END, Endurance; TOT, Total.

Table 7. Functional characteristics of each older healthy subject.

Group O		**Older Healthy Subjects**											
		O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12
Age		80	85	79	75	80	77	75	80	88	81	84	84
Gender		F	M	M	M	F	F	M	F	F	M	M	F
VADL	**AMB**	9	9	16	9	12	12	17	13	22	21	19	15
	FXAL	12	12	13	12	12	12	45	11	13	19	17	11
	INSTR	7	7	14	7	7	7	8	7	10	6	6	5
	TOT	28	28	43	28	31	31	**70**	31	45	46	42	31
DHI	**PHYS**	0	0	0	0	0	8	4	0	2	0	2	0
	FXAL	0	0	2	0	0	8	8	0	2	0	2	0
	EMOT	0	0	2	0	0	0	6	0	0	0	0	0
	TOT	0	0	4	0	0	16	18	0	4	0	4	0
CS-PFP-10	**UPSTR**	48.37	67.95	70.54	79.26	51.43	50.92	68.06	50.92	31.43	42.76	43.52	48.37
	UPFLEX	86.46	84.42	82.64	79.78	67.37	41.69	74.04	81.82	54.36	52.55	64.84	86.46
	LOSTR	55.1	59.85	71.55	71.04	58.5	49.31	57.1	53.83	29.7	30.03	28.05	55.1
	BC	57.85	55.15	84.31	78.08	56.05	52.02	52.84	72.23	34.82	25.03	24.46	57.85
	END	68.16	64.16	80.39	83.54	62.97	59.71	60.78	69.63	39.26	33.37	34.04	68.16
	TOT	61.73	62.47	77.73	79.23	59.01	**53.28**	60.22	64.32	**36.06**	**33.84**	**35.06**	61.73

VADL Total scores greater than 70 = high dependence. DHI Total scores greater than 30 = moderate handicap and scores greater than 60 = high handicap. CS-PFP-10 Total scores less than 47 indicate low physical function and scores between 47 and 56 = moderate function. The total scores achieving moderate to high dependence, moderate to high handicap, and low to moderate physical function are in bold. Abbreviations for the above table are listed in Table 6.

controls received the lowest scores possible on all scores for the VADL and DHI. Patients received the highest scores in these measures and the lowest in the CS-PFP-10, suggesting the poor function as indicated by these measures. Results for within and across group comparisons are provided next.

Across the Experimental Groups

Many significant correlations between objective and subjective functional scales (Tables 9 and 10) indicate several associations between scores of the different tests when all subjects are included. Test outcomes revealed significant positive correlations between all subscale and total scores of the DHI and the VADL. The top panel of Table 11 shows correlations ranged from r=0.66 to r=0.95, so that a high score on the DHI, demonstrating more perceived handicap, corresponded with a high score on the VADL, demonstrating greater perceived dependence during ADLs. All subscale and total scores of the CS-PFP-10, except the Upper Body Flexibility subscale, revealed a significant negative correlation with

Table 8. Mean subjective and objective functional performance scores.

Subscale and Total Scores		Young		Old		Patient	
		mean	(n)	mean	(n)	mean	(n)
VADL	**AMB**	9	13	14.50	12	34.22	9
	FXAL	12	13	15.75	12	46.67	9
	INS	7	13	7.58	12	17.44	9
	TOT	28	13	37.83	12	88.33	9
DHI	**PHYS**	0	13	1.33	12	14.78	9
	FXAL	0	13	1.83	12	16.44	9
	EMOT	0	13	0.67	12	12.11	9
	TOT	0	13	3.83	12	43.33	9
CS-PFP-10	**UPSTR**			55.01	11	36.42	9
	UPFLEX			70.00	11	61.34	9
	LOSTR			51.28	11	39.93	9
	BAL			53.89	11	38.41	9
	END			59.64	11	46.97	9
	TOT			56.63	11	42.96	9

Mean scores for functional performance are shown. The number of subjects (n) included in means is shown. Abbreviations of subscales are listed in Table 6.

the DHI Functional (bottom panel, Table 9) and VADL Ambulation (Table 10) subscales, the two subjective subscales with the greatest positive correlation (r=0.92; top panel, Table 9). These data indicated that greater perceived handicap during functional activities and greater perceived dependence during ADLs requiring walking were associated with greater dependence during the actual performance of ADLs requiring upper body strength, lower body strength, balance and coordination, and endurance. Interestingly, the DHI Emotional subscale revealed a significant negative correlation with the Upper Body Strength subscale score of the CS-PFP-10 (lower panel, Table 9), while the significant negative correlative relationships between the CS-PFP-10 and the VADL total scores mirrored that of the CS-PFP-10 and the VADL Ambulation subscale (Table 10). Perceived and actual abilities were clearly compatible in some aspects for comparisons across all subjects.

Within the Experimental Groups

Within group correlations were not performed on the young control group because these subjects received the lowest possible scores on the DHI and VADL indicating no handicap and no dependence. Furthermore, since Group Y did not perform the CS-PFP-10 due to the lack of normative data for young

Table 9. DHI correlation data across subjects.

Across Groups		DHI			
		PHYS	**FXAL**	**EMOT**	**TOT**
VADL (n=34)	**FXAL**	**0.80**	**0.68**	**0.69**	
	AMB	**0.83**	**0.92**	**0.84**	
	INS	**0.60**	**0.54**	**0.53**	
	TOT				**0.95**
CS-PFP-10 (n=20)	**UPSTR**	-0.45	**-0.68**	**-0.48**	
	UPFLEX	-0.28	-0.26	-0.17	
	LOSTR	-0.23	**-0.51**	-0.30	
	BAL	-0.31	**-0.49**	-0.29	
	END	-0.24	**-0.49**	-0.29	
	TOT				-0.43

Abbreviations are the same as those described in Table 6. Bold text represents p<0.05.

Table 10. VADL correlation data across all older subjects.

Across Groups		VADL			
		FXAL	**AMB**	**INS**	**TOT**
CS-PFP-10 (n=20)	**UPSTR**	-0.27	**-0.69**	-0.23	
	UPFLEX	0.00	-0.25	-0.32	
	LOSTR	-0.10	**-0.55**	-0..07	
	BAL	-0.28	**-0.58**	-0.13	
	END	-0.18	**-0.57**	-0.10	
	TOT				**-0.49**

Abbreviations are the same as those described in Table 6. Bold text represents p<0.05.

controls, tests were performed only to obtain the correlative relationships of subjective and objective functional measures within groups O and P.

There were few significant correlations between scores on functional tests for group O subjects. The top panel of Table 11 shows significant positive correlations existed between the DHI Functional and Emotional subscales and the VADL Functional subscale and indicate that greater perceived functional and emotional handicap is related to greater perceived functional dependence for the healthy older adults. A significant negative correlative relationship also existed between the DHI Physical subscale and the CS-PFP-10 Upper Body Flexibility subscale (lower panel, Table 11), indicating that greater perceived handicap during physical activities was related to lower physical function in tasks requiring upper body flexibility. Table 12 shows a significant negative correlative relationship also existed between the VADL Ambulation subscale and the lower body strength, balance and coordination, and endurance subscales of the CS-PFP-10. A negative association was also found for VADL Ambulation and CS-PFP-10 Upper Body Strength (r=-0.57, Table 12), and although this trend was not significant, it did correspond with that identified when O and P subjects were combined (r=-0.69, Table 10). Thus, greater perceived dependence during ADLs requiring walking was associated with greater dependence during the actual performance of ADLs, especially those requiring lower body strength, balance and coordination, and endurance.

Table 11. DHI vs VADL and CS-PFP-10 correlation data within Group O.

Group O		**DHI**			
		PHYS	**FXAL**	**EMOT**	**TOT**
VADL (n=12)	**FXAL**	0.33	**0.62**	**0.91**	
	AMB	0.11	0.18	0.20	
	INS	-0.23	-0.18	-0.03	
	TOT				**0.62**
CS-PFP-10 (n=11)	**UPSTR**	-0.14	0.07	0.41	
	UPFLEX	**-0.66**	-0.45	0.18	
	LOSTR	-0.21	-0.04	0.26	
	BAL	-0.23	-0.10	0.15	
	END	-0.20	-0.08	0.15	
	TOT				-0.07

Abbreviations are the same as those described in Table 6. Bold text represents p<0.05.

Table 12. VADL vs CS-PFP-10 correlation data within Group O.

Group O		**VADL**			
		FXAL	**AMB**	**INS**	**TOT**
CS-PFP-10 (n=11)	**UPSTR**	0.20	-0.57	0.45	
	UPFLEX	-0.02	-0.53	0.45	
	LOSTR	-0.05	**-0.73**	0.56	
	BAL	-0.20	**-0.64**	0.60	
	END	-0.17	**-0.76**	0.54	
	TOT				-0.28

Abbreviations are the same as those described in Table 6. Bold text represents p<0.05.

Few significant correlations between scores of functional tests were also identified for the P group. The top panel of Table 13 shows that the only significant positive correlation for the subjective scales existed between the VADL Ambulation and DHI Functional subscales. Although negative associations existed between most subscales of the CS-PFP-10 and the DHI Functional (bottom panel, Table 13) and VADL Ambulation (Table 14) subscales, the only correlation to reach significance was between the DHI Functional subscale and the upper body strength subscale of CS-PFP-10. These data suggest that an increase in perceived functional handicap was associated with a greater dependence during the actual performance of ADLs requiring upper body strength in the patients.

Table 13. DHI vs VADL and CS-PFP-10 correlation data within Group P.

Group P		**DHI**			
		PHYS	**FXAL**	**EMOT**	**TOT**
VADL (n=9)	**FXAL**	0.27	-0.05	0.05	
	AMB	0.38	**0.84**	0.58	
	INS	-0.12	-0.14	-0.01	
	TOT				**0.83**
CS-PFP-10 (n=9)	**UPSTR**	0.24	**-0.77**	-0.33	
	UPFLEX	0.42	0.10	0.06	
	LOSTR	0.44	-0.62	-0.19	
	BAL	0.54	-0.49	-0.02	
	END	0.52	-0.55	-0.11	
	TOT				-0.26

Abbreviations are the same as those described in Table 6. Bold text represents p<0.05.

Table 14. VADL vs CS-PFP-10 correlation data within Group P.

Group P		**VADL**			
		FXAL	**AMB**	**INS**	**TOT**
CS-PFP-10 (n=9)	**UPSTR**	0.16	-0.55	0.11	
	UPFLEX	0.49	0.15	-0.57	
	LOSTR	0.33	-0.44	0.10	
	BAL	0.13	-0.47	0.00	
	END	0.25	-0.46	0.05	
	TOT				-0.35

Abbreviations are the same as those described in Table 6. Bold text represents p<0.05.

Summary

Across all three groups, the data indicated that increased perceived handicap during functional activities (DHI Functional) and increased perceived dependence during ADLs requiring walking (VADL Ambulation) were associated with greater dependence during the actual performance of ADLs requiring upper body strength, lower body strength, balance and coordination, and endurance (CS-PFP-10). Correlative relationships within group O mirrored the results stated above. On the other hand, data obtained within group P suggested that an increase in perceived functional handicap was associated with a greater dependence during the actual performance of ADLs requiring upper body strength in the patients.

Exercise Kinematics

Kinematic strategies of head movements used by group P subjects were compared with those in groups Y and O to offer insight to movement differences among groups. Because each marker must be viewed by at least two of the three motion analysis cameras for proper 3D analyses, the greater number of markers required to calculate a variable, especially during the tasks using the whole body (i.e., CoM, hip and ankle angle excursions, and wrist and ankle variability), the greater chance of losing that variable for analyses. Therefore, kinematic variables of the body during the body exercises (ankle sways, circle sways, and ball circles) were excluded as the number of data points were not sufficient for proper analysis. With imminent changes in the number of usable variables expected, associated results included the number of data points used in each analysis. In order to report the results in a concise manner, this portion of the paper was categorized into sections of eye exercises (saccades and visual tracking), head and eye exercises (focusing with head turns, horizontal head movements, targets, and head circles), and body exercises (ankle sways, ball circles, and circle sways). This grouping and the comprehensive overview of movement control during rehabilitation exercises performed by the three groups provided insights into which exercises challenge the deficient head movements in the patient population. For each exercise, except gait with head movement, tables display the group means for the mean maximal angular distance of pitch (Pitch), yaw (Yaw), and roll (Roll) head excursions (in radians), the variability of these excursions (SD), the average timing across cycles in each trial (Timing mean, milliseconds—ms), and the trial temporal variability (Timing SD). The associated r^2 values and p-values from regression analyses and results of the one-way ANOVAs used to further identify between group differences are also displayed. Result descriptions are limited to significant findings for brevity and clarity.

Eye Exercises

During eye exercises, all subjects were instructed to keep the head still. Subjects either rapidly redirected the eyes between playing cards held at eye level in the right and left hands (saccades exercise) or visually tracked the playing card while moving it back and forth with the hand (visual tracking exercise).

Visual Tracking. The minimal overall head movement during the visual tracking exercise shown in Table 15 reveals that subjects kept their heads fairly stable during this exercise. Although the maximal group average was only 0.22 radians (12.61^{o}), a significant effect for age in the yaw plane demonstrated that the older adults had greater yaw head movement and greater variability of this movement than the young adults. ANOVA outcomes parallel these results and revealed differences between group Y and the other two groups exist for yaw excursion. Only differences between group O and Y reached significance for yaw SD (see One-way ANOVAs, Table 15). These data indicate that older subjects from groups P and O moved their heads side-to-side more than group Y while attempting to visually track the playing card they were moving back and forth and that group O subjects do this with greater variability. The regression analysis and ANOVA results for Roll excursion revealed a significant effect for age and patient indicating that group O had greater roll head movement than groups Y and P.

Variability of timing for visual tracking was fairly large for all groups. Although not significantly different across groups, mean timing and SD values for this exercise were always lowest in the Y group.

Table 15. Regression results and group differences during visual tracking.

Visual tracking	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	0.03	55	0.05	35	0.04	20	0.25	0.77	0.01	n/a	0.30	0.80	0.85
Yaw Excursion	0.09	55	0.22	35	0.19	20	**0.00**	0.98	0.17	0.12	**0.00**	**0.00**	0.74
Roll Excursion	0.01	50	0.03	30	0.01	20	**0.00**	**0.00**	0.15	0.41	**0.00**	0.88	**0.00**
Pitch SD	0.01	11	0.07	7	0.01	4	0.18	0.33	0.10	n/a	0.31	1.00	0.50
Yaw SD	0.03	11	0.09	7	0.07	4	**0.02**	0.55	0.27	0.70	**0.01**	0.33	0.54
Roll SD	0.00	10	0.01	6	0.00	4	0.07	0.19	0.19	n/a	0.06	0.97	0.20
Timing mean	177.35	13	208.80	11	219.69	9	0.18	0.62	0.09	n/a	0.53	0.34	0.92
Timing SD	22.09	13	35.18	11	35.21	9	0.23	0.91	0.06	n/a	0.57	0.60	1.00

Excursions are in radians. Time is in milliseconds. Number of data points used for analyses is (n). Bold text represents significant effects ($p<0.05$).

Saccades. Similar to visual tracking, Table 16 demonstrates that overall head movement during the saccades exercise was minimal as the mean maximal head excursion was only 0.09 radians (5.16°). According to the regression analyses, a significant effect for age in all plane excursions revealed that the Y group had less head movement than group O. Results revealed: (1) a significant age and patient effect in the linear regression tests for Yaw and Roll excursions as well as a significant effect of age within group P for Roll Excursion; (2) significant differences between groups Y and O and groups O and P for these measures; and (3) no differences for groups Y and P. Initially, it appeared that the significant age effects for Yaw SD and Roll SD add to these findings; however values less than 0.03 radians (i.e. 2°) are small. Regardless, mean excursion results provided evidence that group O moved their heads more often than the groups Y and P while attempting to perform saccadic eye movements without movement of the head.

A significant age effect was also identified for mean and variable temporal aspects of saccadic eye movements. ANOVA results confirmed some of these findings with significant differences reported between mean cycle saccade time for Y and O groups (Table 16). Unfortunately, timing data were only obtained for 6 of the 9 patients, providing a very low power for ANOVA results. The Y group performed the mean cycle time faster and often with less variability than group O.

Table 16. Regression results and group differences during saccades.

Saccades	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	0.00	65	0.09	50	0.01	30	**0.02**	0.09	0.05	0.20	**0.03**	0.99	0.11
Yaw Excursion	0.00	65	0.06	50	0.02	30	**0.00**	**0.02**	0.14	0.25	**0.00**	0.57	**0.01**
Roll Excursion	0.00	65	0.01	50	0.00	30	**0.00**	**0.02**	0.19	**0.04**	**0.00**	0.23	**0.01**
Pitch SD	0.00	13	0.08	10	0.00	6	0.20	0.35	0.07	n/a	0.36	1.00	0.51
Yaw SD	0.00	13	0.03	10	0.01	6	**0.03**	0.19	0.17	0.29	0.06	0.95	0.24
Roll SD	0.00	13	0.00	10	0.00	6	**0.01**	0.11	0.27	0.20	**0.01**	0.85	0.11
Timing mean	75.11	13	99.72	12	96.20	6	**0.01**	0.91	0.22	0.72	**0.02**	0.14	0.94
Timing SD	7.99	13	14.25	12	7.84	6	**0.02**	0.09	0.22	0.63	0.06	1.00	0.15

Table values are the same as those stated in Table 15.

Head and Eye Exercises

Movements during head and eye exercises emphasized rotational head movements with and without eye movement relative to the head and/or external environment (see methods for details of each exercise). Tables 17 through 21 displayed the same variables used in Tables 15 and 16 for eye exercises. There are five tables for the four head and eye exercises because head circles were separated into left and right directions.

Focusing with Head Turns. Table 17 shows a significant effect of age for the yaw plane and demonstrates that the Y group had a greater amount of yaw head movement and less variability of this movement than the group O. A significant effect of age within patients for yaw excursion was also found. These results indicated that older patients moved their heads less in the yaw direction and with greater variability than younger patients.

The significant age effect for timing SD and differences between Y and O groups for this measure suggest that the O group had the greatest variability in cycle time for performance of this exercise. Note that timing means and SD for the Y group were the lowest once again.

Head Circles. Tables 18 and 19 depict the group performance during head circles in the left and right directions, respectively. Significant age effects of head Roll excursion in both directions and within patients, as well as age effects on Yaw excursions for rightward head circles and mean and variable cycle time for leftward head circles existed. The Y group performed larger movements than the O group

Table 17. Regression results and group differences during focusing with head turns.

Focusing with Head Turns	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	0.07	65	0.11	55	0.11	45	0.27	0.59	0.01	n/a	0.17	0.20	1.00
Yaw Excursion	1.12	65	0.89	55	1.02	45	**0.00**	0.08	0.13	**0.02**	**0.00**	0.15	0.08
Roll Excursion	0.19	65	0.10	55	0.10	45	0.29	0.74	0.01	n/a	0.35	0.39	1.00
Pitch SD	0.02	13	0.05	11	0.10	9	0.89	0.12	0.10	n/a	0.77	0.15	0.45
Yaw SD	0.05	13	0.18	11	0.12	9	**0.00**	0.32	0.27	0.55	**0.00**	0.19	0.26
Roll SD	0.18	13	0.02	11	0.01	9	0.53	0.75	0.02	n/a	0.60	0.60	1.00
Timing mean	114.94	13	143.37	12	139.96	9	0.10	0.99	0.09	n/a	0.36	0.50	0.99
Timing SD	8.86	13	27.27	12	17.50	9	**0.00**	0.16	0.37	0.60	**0.003**	0.21	0.18

Table values are the same as those stated in Table 15.

Table 18. Regression results and group differences for head circles in the left direction.

Head Circles Left	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	1.05	55	1.01	55	1.00	45	0.47	0.94	0.00	n/a	0.84	0.84	1.00
Yaw Excursion	0.97	55	1.03	55	1.17	45	0.71	0.07	0.03	n/a	0.73	0.07	0.30
Roll Excursion	0.23	55	0.12	55	0.17	45	**0.00**	0.13	0.12	**0.00**	**0.00**	0.16	0.16
Pitch SD	0.16	11	0.09	11	0.12	9	0.17	0.69	0.07	n/a	0.41	0.78	0.85
Yaw SD	0.10	11	0.11	11	0.19	9	0.93	0.06	0.13	n/a	0.95	0.15	0.25
Roll SD	0.06	11	0.02	11	0.02	9	0.14	0.82	0.09	n/a	0.37	0.39	1.00
Timing mean	167.98	13	233.35	12	220.80	9	**0.02**	0.93	0.19	0.09	0.07	0.20	0.93
Timing SD	7.17	13	18.30	12	21.77	9	**0.00**	0.25	0.38	**0.04**	**0.02**	**0.01**	0.72

Table values are the same as those stated in Table 15.

Table 19. Regression results and group differences for head circles in the right direction.

Head Circles Right	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	0.98	50	1.08	50	1.06	40	0.17	0.86	0.12	n/a	0.41	0.64	0.95
Yaw Excursion	0.81	50	1.21	50	1.19	40	**0.00**	0.60	0.36	**0.01**	**0.00**	**0.00**	0.96
Roll Excursion	0.20	50	0.13	50	0.14	40	**0.02**	1.00	0.22	**0.00**	**0.03**	0.10	0.92
Pitch SD	0.11	10	0.16	10	0.09	8	0.39	0.31	0.23	n/a	0.74	0.94	0.57
Yaw SD	0.11	10	0.12	10	0.12	8	0.72	0.98	0.08	n/a	0.94	0.95	1.00
Roll SD	0.06	10	0.06	10	0.02	8	0.93	0.41	0.18	n/a	0.99	0.65	0.74
Timing mean	207.15	13	235.65	12	208.80	9	0.35	0.59	0.03	n/a	0.58	0.97	0.78
Timing SD	27.6	13	35.98	12	34.61	9	0.66	0.97	0.01	n/a	0.86	0.91	1.00

Table values are the same as those stated in Table 15.

in terms of Roll excursions. A significant age effect within the patient group demonstrated that the older patients performed the exercise with less roll movements in both directions and greater yaw movements for head circles in the right direction than the younger patients.

A significant effect of age for Timing mean and SD only existed for head circles in the leftward direction. The Y group generally performed the trials faster and with less cycle duration variability than the other groups, but all groups had greater timing variability means in the rightward direction (compare Timing SDs in Table 19 to those in Table 18).

Horizontal Head Movements. Table 20 shows the results of performance during the horizontal head movements exercise. Significant patient effects as well as several corresponding significant group differences between the P group and the other groups were evident for mean and/or SD head excursions in the different planes. Further examinations of the group mean scores reveal that the P group performed this exercise with greater pitch and less roll excursions than controls and with greater variability than group O in the yaw plane.

Table 20. Regression results and group differences for horizontal head movements.

Horizontal Head Movements	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	0.08	65	0.12	60	0.23	45	0.12	**0.00**	0.32	n/a	0.39	**0.00**	**0.01**
Yaw Excursion	1.84	65	1.71	60	1.77	45	0.10	0.64	0.13	n/a	0.19	0.65	0.75
Roll Excursion	0.17	65	0.17	60	0.14	45	0.41	**0.00**	0.29	n/a	0.84	**0.00**	**0.01**
Pitch SD	0.02	13	0.02	12	0.17	9	0.71	**0.04**	0.41	n/a	1.00	0.08	0.10
Yaw SD	0.07	13	0.10	12	0.31	9	0.55	**0.02**	0.47	n/a	0.94	**0.03**	0.06
Roll SD	0.01	13	0.02	12	0.01	9	0.16	0.30	0.27	n/a	0.28	0.99	0.42
Timing mean	300.51	13	318.63	12	313.22	9	0.29	0.88	0.04	n/a	0.67	0.83	0.98
Timing SD	11.57	13	20.01	12	13.28	9	0.11	0.26	0.09	n/a	0.28	0.99	0.41

Table values are the same as those stated in Table 15.

Targets. Minimal differences among groups were revealed during performance of the targets exercise (Table 21). The only significant difference identified was between Y and P groups for the roll excursion, offering no insight to patient or aging effects.

Body Exercises

During body exercises, all subjects were to move their whole body, excluding the feet, through space. Circular motion in multiple body segments included the head and/or the eyes. Missing data points were common for many of the body markers during performance of body exercises, thus kinematic

Table 21. Regression results and group differences during targets.

Targets	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	0.12	55	0.10	60	0.18	45	0.93	0.12	0.13	n/a	0.88	0.44	0.21
Yaw Excursion	1.74	55	1.66	60	1.74	45	0.29	0.41	0.09	n/a	0.66	1.00	0.67
Roll Excursion	0.17	50	0.16	60	0.15	45	0.06	0.30	0.20	n/a	0.08	**0.03**	0.84
Pitch SD	0.12	11	0.03	12	0.17	9	0.65	0.23	0.22	n/a	0.52	0.88	0.29
Yaw SD	0.17	11	0.13	12	0.14	9	0.69	0.79	0.08	n/a	0.92	0.95	1.00
Roll SD	0.01	10	0.01	12	0.00	9	0.55	0.35	0.19	n/a	0.98	0.71	0.80
Timing mean	192.94	13	219.40	12	220.16	9	0.11	0.80	0.10	n/a	0.29	0.32	1.00
Timing SD	40.60	13	28.92	12	13.27	9	0.52	0.37	0.06	n/a	0.85	0.39	0.70

Table values are the same as those stated in Table 15.

analyses for ankle sways, leftward and rightward circle sways, as well as leftward and rightward ball circles were limited to head movement variables and temporal data used previously. Results for the gait with head movement exercise differ from other exercises due to the large movements required for its performance. The Qualisys motion system was not appropriate for such recordings, thus a standard video camera was used instead. Variables determined for this exercise were quantified as described in the methods; however some of these were used merely for descriptive purposes.

Ankle Sways. Table 22 reveals significant effects of age and patient for Pitch, Yaw, and Roll head excursions. The significant group differences between the O group and each of the remaining groups in all planes show that the Y and P groups moved their heads less than the older controls in all three planes.

Table 22. Regression results and group differences during ankle sways.

Ankle Sways	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	0.22	60	0.36	60	0.19	45	**0.00**	**0.00**	**0.16**	0.21	**0.00**	0.77	**0.00**
Yaw Excursion	0.07	60	0.13	60	0.07	45	**0.01**	**0.04**	**0.05**	0.13	**0.02**	1.00	**0.04**
Roll Excursion	0.08	35	0.13	36	0.04	30	**0.01**	**0.00**	**0.16**	0.33	**0.03**	0.16	**0.00**
Pitch SD	0.05	12	0.08	12	0.05	9	0.15	0.20	0.09	n/a	0.31	1.00	0.33
Yaw SD	0.02	12	0.06	12	0.02	9	0.18	0.41	0.06	n/a	0.44	0.97	0.63
Roll SD	0.02	7	0.06	8	0.02	6	0.21	0.23	0.12	n/a	0.45	0.99	0.42
Timing mean	192.68	13	192.93	12	198.84	9	0.68	0.90	0.01	n/a	1.00	0.96	0.97
Timing SD	13.63	13	18.60	12	26.33	9	0.15	0.14	0.18	n/a	0.59	0.07	0.36

Table values are the same as those stated in Table 15.

Circle Sways. Tables 23 and 24 show age and patient effects on circle sways. In many cases the O group demonstrated significantly greater head excursions than Y and P groups. ANOVAs revealed consistent differences for the pitch and yaw excursions, however roll excursions only varied between O and P groups. Greater yaw head excursions in the P group were also identified compared to Y group.

Patients' mean variability of cycle timing was higher than the other groups. Only Y and P group differences were identified as significant.

Table 23. Regression results and group differences during circle sways in the left direction.

Circle Sways Left	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	0.15	60	0.36	55	0.22	45	**0.00**	**0.04**	**0.10**	0.65	**0.00**	0.40	**0.03**
Yaw Excursion	0.13	60	0.44	55	0.26	45	**0.00**	**0.02**	**0.18**	0.79	**0.00**	**0.04**	**0.01**
Roll Excursion	0.17	30	0.25	38	0.12	20	**0.04**	**0.01**	**0.09**	**0.00**	0.17	0.67	**0.04**
Pitch SD	0.04	12	0.09	11	0.10	9	0.32	0.64	0.06	n/a	0.60	0.44	0.95
Yaw SD	0.04	12	0.10	11	0.15	9	0.26	0.29	0.12	n/a	0.53	0.16	0.67
Roll SD	0.08	6	0.09	8	0.03	4	0.83	0.33	0.06	n/a	0.99	0.71	0.62
Timing mean	192.94	13	219.40	12	220.16	9	0.11	0.80	0.10	n/a	0.29	0.32	1.00
Timing SD	40.60	13	28.92	12	13.27	9	0.52	0.37	0.06	n/a	0.85	0.39	0.70

Table values are the same as those stated in Table 15.

Table 24. Regression results and group differences during circle sways in the right direction.

Circle Sways Right	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	0.17	65	0.35	48	0.17	44	**0.00**	**0.00**	**0.13**	0.37	**0.00**	0.98	**0.00**
Yaw Excursion	0.16	65	0.34	46	0.27	44	**0.00**	0.48	**0.08**	**0.00**	**0.00**	**0.04**	**0.04**
Roll Excursion	0.13	39	0.14	33	0.13	42	0.34	0.64	0.01	n/a	0.90	0.99	**0.00**
Pitch SD	0.05	13	0.14	10	0.06	9	0.104	0.27	0.10	n/a	0.23	0.96	0.33
Yaw SD	0.03	13	0.09	10	0.11	9	0.13	0.27	0.17	n/a	0.17	**0.04**	0.63
Roll SD	0.09	9	0.08	7	0.04	9	0.96	0.32	0.06	n/a	0.97	0.51	0.42
Timing mean	209.88	13	209.23	12	232.31	9	0.79	0.30	0.02	n/a	1.00	0.75	0.97
Timing SD	17.19	13	31.41	12	65.56	9	0.49	**0.00**	0.33	n/a	0.43	**0.00**	0.36

Table values are the same as those stated in Table 15.

Ball Circles. Significant age effects for yaw excursions in the ball circles exercise show that the Y group exhibited significantly greater head excursions than the other groups in this plane in the rightward direction (Table 26). This difference was limited to O and Y group differences for the leftward direction (Table 25). Although the P group had the lowest mean pitch head excursion of the three groups for both directions of the ball circle exercise, the differences were only significant in the rightward direction between the Y and P groups. These data suggest that the Y group moved their heads more than the other groups, especially in the yaw plane, in about the same amount of time.

Table 25. Regression results and group differences during ball circles in the left direction.

Ball Circles Left	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	1.05	65	0.99	59	0.86	45	0.60	0.09	0.03	n/a	0.80	0.10	0.31
Yaw Excursion	1.75	63	1.46	57	1.51	45	**0.00**	0.83	0.08	0.17	**0.01**	0.06	0.90
Roll Excursion	0.35	59	0.32	52	0.28	43	0.97	0.09	0.02	n/a	0.71	0.12	0.46
Pitch SD	0.20	13	0.25	12	0.13	9	0.79	0.31	0.03	n/a	0.85	0.79	0.50
Yaw SD	0.20	13	0.22	12	0.21	9	0.78	0.91	0.00	n/a	0.93	0.99	0.98
Roll SD	0.05	12	0.06	11	0.05	9	0.46	0.69	0.02	n/a	0.86	0.99	0.92
Timing mean	192.94	13	219.40	12	220.16	9	0.11	0.80	0.10	n/a	0.29	0.32	1.00
Timing SD	40.60	13	28.92	12	13.27	9	0.52	0.37	0.06	n/a	0.85	0.39	0.70

Table values are the same as those stated in Table 15.

Table 26. Regression results and group differences during ball circles in the right direction.

Ball Circles Right	**Young**		**Old**		**Patient**		**Regressions**				**One-way ANOVAs**		
	Mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Pitch Excursion	1.13	65	1.04	55	0.85	35	0.31	**0.04**	**0.05**	n/a	0.60	**0.02**	0.14
Yaw Excursion	1.76	64	1.38	55	1.41	38	**0.00**	0.96	**0.16**	**0.03**	**0.00**	**0.00**	0.94
Roll Excursion	0.29	64	0.31	54	0.34	38	0.33	0.25	0.02	n/a	0.70	0.18	0.57
Pitch SD	0.15	13	0.12	11	0.07	7	0.80	0.33	0.05	n/a	0.87	0.43	0.71
Yaw SD	0.18	13	0.11	11	0.17	8	0.29	0.44	0.05	n/a	0.48	1.00	0.61
Roll SD	0.06	13	0.08	11	0.05	8	0.57	0.50	0.02	n/a	0.78	0.98	0.73
Timing mean	200.28	13	244.16	11	245.00	9	0.11	0.83	0.10	n/a	0.31	0.33	1.00
Timing SD	9.11	13	13.61	11	16.69	9	0.10	0.33	0.16	n/a	0.15	0.96	0.34

Table values are the same as those stated in Table 15.

Gait with Head Movement. Table 27 displays the various descriptive data calculated during the video-recordings of subjects performing the gait with head movement exercise. Regression analyses reveal age effects that resulted in the Y group demonstrating the shortest gait time, the fewest number of steps, and the fastest cadence during task performance. Patient effects were also noted for step number and cadence so that the O group used fewer steps and had a faster cadence than the P group. The significant age within patient effects for gait time and step cadence shows that older patients had longer gait durations and slower step cadence than younger patients.

Review of video also revealed several observations used for descriptive analyses, which are presented in the last four rows of Table 27. The Y group had no stumbles, no need for support, and no occurrences of veering off the designated straight path. These numbers increased for the O group and were largest for the P group. Patients veered off their original path toward the direction of the starting head turn for that particular trial (i.e., if trial began with right head turn, the patient veered to the right). It is evident that the P group had the most difficulty in following task instructions, while group O had some difficulties in this regard, group Y had none.

Table 27. Descriptive statistics of observations of gait with head movement.

Gait with Head Movement	**Young (n=60)**		**Old (n=72)**		**Patient (n=48)**		**Regressions**				**One-way ANOVAs**		
	mean	**SD**	**mean**	**SD**	**mean**	**SD**	**AGE**	**PAT**	**r^2**	**PAT(AGE)**	**Y vs O**	**Y vs P**	**O vs P**
Gait Time	6.25	1.12	11.00	1.02	12.48	1.27	**0.00**	0.14	**0.09**	**0.01**	**0.01**	**0.00**	0.63
Step Number	12.55	0.40	14.20	0.37	15.81	0.45	**0.00**	**0.00**	**0.16**	0.17	**0.01**	**0.00**	**0.01**
Step Cadence	2.07	0.05	1.56	0.05	1.38	0.06	**0.00**	**0.00**	**0.40**	**0.00**	**0.00**	**0.00**	**0.03**
Number of Imbalances	0		2		13								
Need for Support	0		12		48								
Veer to Left	0		1		10								
Veer to Right	0		8		12								

Mean values (standard deviations) for gait time, number of steps and cadence are provided for each group. Number of total occurrences is provided for remaining variables. Bold text represents $p<0.05$.

Summary

Results of kinematic performance across groups revealed that when the goal of the exercise is to keep the head still (i.e., visual tracking, saccades, ankle sways, and circles sways), the older controls moved their heads with the greatest excursions. If differences did exist, patients commonly moved their heads more than the young controls. For several exercises where head movement was part of the task (i.e. focusing with head turns, head circles, and ball circles), the young controls demonstrated the greatest head movements. However, in two exercises, the patient group performed altered head movements from that of the young and older control groups (i.e., greater Pitch and less Roll excursion in horizontal head movements and Yaw excursions greater than young controls and less than older controls in circle sways exercise). In addition, the young controls performed at a faster pace and less variability than the other groups in the few cases where temporal differences were identified.

Exercise Kinematics and Functional Measures

In the third part of the study physical function measures were compared to the kinematic variables obtained during exercise performance to help better understand possible control strategies used by the three groups and offer insight to the advancement of vestibular rehabilitation. As organized in the previous section, this portion of the manuscript was categorized into sections of eye exercises, head and eye exercises, and body exercises. Results of Pearson-Product Moment Correlations (PPMC) provided significant associations between the kinematic parameters and the scales of the VADL, DHI, and CS-PFP-10 across the three experimental groups.

Eye Exercises

Kinematic and functional correlation outcomes were different for the two eye exercises. During the visual tracking exercise, significant positive correlations between YAW variability and most scales of the CS-PFP-10 existed so that greater head movement variability in the yaw plane corresponded to higher physical function scores (Table 28). Thus, some head movement variability in the direction of task performance was associated with better upper body flexibility, lower body strength, balance and coordination, and endurance. Cycle time variability for visual tracking was negatively correlated to most scales of the CS-PFP-10 so that lower actual functional abilities were associated with greater variability in the time to perform the cycles (Table 28). No significant temporal associations were identified for saccades (Table 29). Spatial and temporal kinematics during the visual tracking exercise were associated with actual functional performance across subjects.

Head and Eye Exercises

In general, for the head and eye exercises, positive correlations transpired between the various head excursion parameters and the CS-PFP-10 scores. Significant positive correlations between head

Table 28. Correlations between kinematic parameters and functional variables for visual tracking.

Visual tracking		Kinematic Parameters							
		Head Excursions mean			Head Excursions SD			Timing	
		PITCH (n=22)	YAW (n=22)	ROLL (n=22)	PITCH (n=22)	YAW (n=22)	ROLL (n=20)	mean (n=32)	SD (n=32)
VADL	FXAL	0.03	0.36	0.02	-0.11	0.40	0.06	0.24	0.06
	AM	-0.01	0.31	0.02	-0.16	0.17	0.00	0.30	0.31
	INS	0.02	0.24	0.15	-0.09	-0.03	0.14	-0.01	-0.09
	TOT	0.02	**0.46**	0.12	-0.14	0.27	0.14	0.27	0.19
DHI	PHYS	0.04	0.27	-0.04	-0.12	0.15	-0.05	0.24	0.14
	FXAL	0.02	0.40	0.06	-0.12	0.16	0.06	0.29	0.29
	EMOT	0.04	0.34	0.05	-0.11	0.10	0.05	0.16	0.05
	TOT	0.04	0.35	0.02	-0.11	0.14	0.02	0.24	0.18
CS-PFP-10	UPSTR	-0.01	0.25	0.41	0.02	0.59	0.57	-0.04	-0.45
	UPFLX	0.44	0.20	0.16	0.46	**0.72**	0.43	-0.44	**-0.54**
	LOSTR	0.19	0.41	0.35	0.21	**0.77**	0.56	-0.14	**-0.52**
	BC	0.24	0.46	0.45	0.23	**0.65**	0.58	-0.30	**-0.48**
	END	0.34	0.44	0.36	0.33	**0.75**	0.56	-0.28	**-0.54**
	TOT	0.26	0.43	0.41	0.27	**0.76**	0.60	-0.25	**-0.54**

Abbreviations for functional data are the same as those described in Table 6. Bold text represents p<0.05. Correlation n of CS-PFP-10 and Head Excursion data was 10 for each parameter while correlation n of CS-PFP-10 and Timing data was 18 for each parameter.

Table 29. Correlations between kinematic parameters and functional variables for saccades.

Saccades		Kinematic Parameters							
		Head Excursions mean			Head Excursions SD			Timing	
		PITCH (n=29)	YAW (n=29)	ROLL (n=29)	PITCH (n=29)	YAW (n=29)	ROLL (n=29)	mean (n=31)	SD (n=31)
VADL	FXAL	-0.11	-0.08	-0.06	-0.11	-0.09	-0.09	0.27	-0.01
	AM	-0.11	0.01	0.06	-0.11	-0.06	-0.02	0.17	-0.14
	INS	-0.10	-0.03	0.06	-0.11	-0.09	-0.02	0.19	-0.14
	TOT	-0.11	-0.04	0.00	-0.11	-0.08	-0.06	0.20	-0.12
DHI	PHYS	-0.11	-0.05	-0.03	-0.11	-0.10	-0.10	0.14	-0.15
	FXAL	-0.10	-0.05	-0.03	-0.11	-0.08	-0.10	0.21	-0.12
	EMOT	-0.04	-0.04	-0.03	-0.03	-0.08	-0.10	0.14	-0.16
	TOT	-0.10	-0.05	-0.03	-0.10	-0.09	-0.09	0.17	-0.15
CS-PFP-10	UPSTR	0.00	0.01	-0.05	0.00	0.05	0.06	0.29	0.35
	UPFLX	0.37	0.40	0.42	0.37	0.44	0.51	-0.07	0.25
	LOSTR	0.16	0.10	0.30	0.17	0.16	0.12	-0.04	0.23
	BC	0.17	0.12	0.07	0.18	0.16	0.12	-0.09	0.10
	END	0.23	0.17	0.10	0.24	0.22	0.22	-0.13	0.21
	TOT	0.20	0.15	0.09	0.21	0.21	0.19	-0.04	0.23

Abbreviations for functional data are the same as those described in Table 6. Bold text represents p<0.05. Correlation n of CS-PFP-10 and Head Excursion data was 15 for each parameter while correlation n of CS-PFP-10 and Timing data was 17 for each parameter.

movements in at least one plane and the actual performance in ADLs requiring lower body strength, balance and coordination, and endurance existed for focusing with head turns (Table 30), left (Table 31) and right (Table 32) head circles, and horizontal head movements (Table 33) exercises. These relationships indicated that the greater head movement in these exercises, particularly in the yaw direction, the higher function in activities involving lower body strength, balance and coordination, and endurance.

Table 30. Correlations between kinematic parameters and functional variables for focusing with head turns.

Focusing with Head Turns		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=33)	**YAW (n=33)**	**ROLL (n=33)**	**PITCH (n=33)**	**YAW (n=33)**	**ROLL (n=33)**	**mean (n=34)**	**SD (n=34)**
VADL	**FXAL**	**0.56**	-0.15	-0.32	**0.76**	0.31	-0.09	0.10	0.02
	AM	0.18	-0.26	**-0.47**	0.33	0.26	-0.12	0.20	0.20
	INS	0.00	0.01	-0.18	0.09	0.09	-0.10	0.15	0.14
	TOT	0.26	-0.20	**-0.46**	**0.38**	0.21	-0.12	0.17	0.14
DHI	**PHYS**	0.23	-0.06	-0.31	**0.38**	0.08	-0.12	0.13	0.09
	FXAL	0.17	-0.14	**-0.38**	0.24	0.09	-0.11	0.13	0.13
	EMOT	0.21	-0.12	**-0.36**	0.32	0.08	-0.09	0.16	0.04
	TOT	0.21	-0.11	**-0.37**	0.32	0.09	-0.11	0.15	0.09
CS-PFP-10	**UPSTR**	0.37	0.42	0.42	0.08	-0.13	-0.13	0.20	-0.06
	UPFLX	0.32	0.18	0.33	0.27	0.06	0.08	0.32	**-0.49**
	LOSTR	0.38	**0.50**	**0.49**	0.15	-0.25	-0.26	0.21	-0.32
	BC	0.24	**0.46**	**0.46**	-0.02	-0.32	-0.32	0.14	-0.35
	END	0.32	**0.49**	**0.50**	0.09	-0.28	-0.27	0.16	-0.39
	TOT	0.35	**0.48**	**0.50**	0.09	-0.25	-0.24	0.19	-0.34

Abbreviations for functional data are the same as those described in Table 6. Bold text represents $p<0.05$. Correlation n of CS-PFP-10 and Head Excursion data was 19 for each parameter while correlation n of CS-PFP-10 and Timing data was 20 for each parameter.

Interestingly, significant positive correlations also existed between several perceived functional scores and pitch head excursions and the variability of Pitch and Yaw excursions during horizontal head movements (Table 33). The data indicate that the greater pitch head movement and greater head movement variability in pitch and/or yaw directions during the horizontal head movement exercise, the greater the perceived handicap and perceived physical dependence. Significant positive correlations were also found between VADL scales and head excursions for the targets exercise (Table 34) so that

Table 31. Correlations between kinematic parameters and functional variables for head circles left.

Head Circles Left		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=31)	**YAW (n=31)**	**ROLL (n=31)**	**PITCH (n=31)**	**YAW (n=31)**	**ROLL (n=31)**	**mean (n=34)**	**SD (n=34)**
VADL	**FXAL**	-0.07	0.08	-0.21	-0.03	0.10	-0.18	0.22	0.30
	AM	-0.06	0.03	-0.21	-0.09	0.22	-0.21	**0.38**	**0.49**
	INS	0.14	0.26	0.14	-0.01	**0.53**	-0.08	0.23	**0.54**
	TOT	-0.05	0.12	-0.16	-0.09	0.23	-0.21	**0.41**	**0.59**
DHI	**PHYS**	0.05	0.21	-0.04	-0.03	**0.35**	-0.17	0.21	0.46
	FXAL	-0.08	0.05	-0.06	-0.06	0.31	-0.17	0.33	**0.57**
	EMOT	0.02	0.13	-0.12	-0.06	0.29	-0.16	**0.38**	**0.65**
	TOT	-0.01	0.13	-0.07	-0.05	0.33	-0.17	0.32	**0.58**
CS-PFP-10	**UPSTR**	0.19	0.27	-0.05	0.08	-0.10	0.19	-0.13	-0.17
	UPFLX	0.16	-0.07	0.34	**0.51**	0.39	0.38	-0.37	**-0.49**
	LOSTR	**0.48**	**0.55**	0.04	0.15	-0.08	0.13	-0.20	-0.22
	BC	**0.56**	**0.51**	0.12	0.13	0.02	0.08	-0.27	-0.21
	END	**0.56**	**0.56**	0.14	0.17	0.02	0.12	-0.29	-0.25
	TOT	**0.49**	**0.49**	0.11	0.17	0.00	0.14	-0.26	-0.25

Abbreviations for functional data are the same as those described in Table 6. Bold text represents p<0.05. Correlation n of CS-PFP-10 and Head Excursion data was 19 for each parameter while correlation n of CS-PFP-10 and Timing data was 20 for each parameter.

Table 32. Correlations between kinematic parameters and functional variables for head circles right.

Head Circles Right		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=28)	**YAW (n=28)**	**ROLL (n=28)**	**PITCH (n=28)**	**YAW (n=28)**	**ROLL (n=28)**	**mean (n=33**	**SD (n=33)**
VADL	**FXAL**	-0.04	0.09	-0.28	-0.18	-0.05	-0.21	0.08	0.16
	AM	-0.11	0.06	-0.27	-0.15	-0.02	-0.23	0.08	0.09
	INS	0.14	0.25	0.05	-0.01	0.08	-0.06	0.01	0.08
	TOT	-0.09	0.13	-0.24	-0.16	-0.01	-0.24	0.13	0.20
DHI	**PHYS**	-0.05	0.12	-0.18	-0.19	0.03	-0.21	-0.03	0.06
	FXAL	-0.13	0.02	-0.18	-0.13	0.00	-0.19	0.04	0.11
	EMOT	-0.10	0.02	-0.18	-0.09	0.02	-0.17	0.09	0.15
	TOT	-0.10	0.05	-0.19	-0.14	0.01	-0.20	0.03	0.11
CS-PFP-10	**UPSTR**	**0.50**	**0.57**	0.20	0.16	0.19	0.26	0.15	0.09
	UPFLX	0.38	0.17	**0.51**	0.42	0.25	0.33	-0.14	-0.24
	LOSTR	**0.64**	**0.61**	0.24	0.14	0.20	0.19	-0.04	-0.09
	BC	**0.64**	**0.56**	0.29	0.08	0.12	0.12	-0.19	-0.21
	END	**0.62**	**0.55**	0.30	0.12	0.16	0.15	-0.17	-0.19
	TOT	**0.63**	**0.57**	0.29	0.14	0.17	0.18	-0.11	-0.14

Abbreviations for functional data are the same as those described in Table 6. Bold text represents p<0.05. Correlation n of CS-PFP-10 and Head Excursion data was 17 for each parameter while correlation n of CS-PFP-10 and Timing data was 20 for each parameter.

greater movements in the pitch direction during this exercise were linked to greater perceived dependence. Significant negative correlations with subjective functional performance were discovered for Roll excursion during focusing with head turns (Table 30) and horizontal head movements (Table 33). Smaller head movements in roll are linked to greater dependence and/or handicap for the focusing with head turns (Table 30) and horizontal head movements (Table 33) exercises in the current subjects.

With the exception of head circles to the left, the temporal patterns of head movements during the head and eye exercises rarely exhibited significant correlations with the subjective and objective functional parameters. When significant correlations were determined, they were positive between the mean cycle time and variability with subjective scales (Table 31) and negative with objective findings in the CS-PFP-10 (Tables 30 and 31). Longer cycle times and greater temporal variability were associated with increased perceived handicap and dependence and lower function in activities involving upper body flexibility for the given exercises.

Table 33. Correlations between kinematic parameters and functional variables for horizontal head movements.

Horizontal Head Movement		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=34)	**YAW (n=34)**	**ROLL (n=34)**	**PITCH (n=34)**	**YAW (n=34)**	**ROLL (n=34)**	**mean (n=33)**	**SD (n=33)**
VADL	**FXAL**	**0.36**	-0.08	-0.24	0.23	**0.36**	0.05	0.10	-0.09
	AM	**0.57**	-0.17	**-0.48**	**0.45**	**0.61**	0.07	0.11	0.03
	INS	0.32	-0.01	-0.10	0.08	0.14	-0.05	0.09	0.06
	TOT	**0.61**	-0.17	**-0.43**	**0.40**	**0.59**	0.00	0.13	0.00
DHI	**PHYS**	**0.52**	-0.08	-0.30	**0.35**	**0.46**	-0.09	0.12	-0.07
	FXAL	**0.48**	-0.19	**-0.50**	**0.37**	**0.52**	-0.09	0.13	-0.08
	EMOT	**0.40**	-0.17	**-0.38**	0.23	**0.37**	-0.06	0.11	-0.05
	TOT	**0.49**	-0.16	**-0.42**	0.33	**0.48**	-0.08	0.12	-0.07
CS-PFP-10	**UPSTR**	-0.19	0.38	**0.63**	-0.39	-0.35	-0.15	0.02	0.33
	UPFLX	-0.37	0.24	0.38	-0.37	-0.24	-0.11	-0.27	0.20
	LOSTR	-0.13	0.44	**0.61**	-0.37	-0.29	-0.37	-0.14	0.13
	BC	-0.20	0.34	**0.50**	-0.38	-0.36	-0.44	-0.21	0.07
	END	-0.19	0.41	**0.59**	-0.40	-0.34	-0.41	-0.19	0.07
	TOT	-0.20	0.41	**0.60**	-0.41	-0.35	-0.37	-0.17	0.12

Abbreviations for functional data are the same as those described in Table 6. Bold text represents p<0.05. Correlation n of CS-PFP-10 and Head Excursion data was 20 for each parameter while correlation n of CS-PFP-10 and Timing data was 19 for each parameter.

Table 34. Correlations between kinematic parameters and functional variables for targets.

Targets		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=34)	**YAW (n=34)**	**ROLL (n=34)**	**PITCH (n=34)**	**YAW (n=34)**	**ROLL (n=34)**	**mean (n=33)**	**SD (n=33)**
VADL	**FXAL**	**0.57**	-0.06	-0.11	**0.39**	0.05	-0.11	0.19	-0.11
	AM	**0.42**	0.09	0.07	0.25	0.09	-0.08	0.23	-0.18
	INS	-0.05	0.22	0.20	-0.17	-0.08	-0.02	-0.03	-0.25
	TOT	**0.35**	0.11	0.07	0.18	-0.02	-0.14	0.22	-0.20
DHI	**PHYS**	0.33	0.10	0.04	0.20	-0.04	-0.14	0.18	-0.20
	FXAL	0.31	0.09	0.07	0.19	-0.02	-0.14	0.15	-0.23
	EMOT	0.26	0.08	0.05	0.14	-0.04	-0.12	0.14	-0.21
	TOT	0.32	0.09	0.05	0.19	-0.03	-0.14	0.16	-0.22
CS-PFP-10	**UPSTR**	-0.20	0.09	-0.08	-0.23	**-0.45**	-0.22	-0.11	0.07
	UPFLX	0.21	-0.14	-0.15	0.14	-0.04	-0.15	-0.23	0.13
	LOSTR	-0.04	0.02	-0.22	-0.08	-0.35	-0.20	-0.35	0.00
	BC	-0.16	0.00	-0.22	-0.15	-0.34	-0.15	-0.44	-0.09
	END	-0.10	0.02	-0.21	-0.12	-0.34	-0.17	-0.39	-0.04
	TOT	-0.11	0.02	-0.19	-0.13	-0.36	-0.19	-0.36	-0.02

Abbreviations for functional data are the same as those described in Table 6. Bold text represents $p<0.05$. Correlation n of CS-PFP-10 and Head Excursion data was 20 for each parameter while correlation n of CS-PFP-10 and Timing data was 19 for each parameter.

Body Exercises

While only one significant correlation was identified for Yaw excursion and upper body flexibility for circle sways right (Table 37) and one significant correlation was identified for variability of Yaw excursion in circle sways left and the VADL Functional subscale (Table 36), several significant correlations were identified between the kinematic parameters and objective functional scores for the ball circles exercise (Tables 38 and 39). For circle sways right greater yaw excursion of the head was associated with greater upper body flexibility and for circle sways left the greater variability of yaw head excursions was associated with greater perceived dependence. Several positive correlations were identified between pitch and yaw head excursions and the CS-PFP-10 during the ball circles exercises (Tables 38 and 39). These relationships were most dominant between pitch head excursions and subscales of the CS-PFP-10 involving lower body strength, balance and coordination, and endurance when both directions were considered including the right direction. Therefore, greater head movement, especially in the pitch planes, during the ball circles exercise was related to increased physical functional performance during ADLs primarily involving the lower body.

Examination of cycle time and its variability during the body exercises revealed several positive correlations between the subjective functional scales and temporal variability, especially for ankle sways (Table 35) and circle sways exercises (Tables 36 and 37). These findings suggest longer cycle durations are associated with greater perceived handicap and dependence. Moreover, temporal variability of ball circles to the right exhibited significant negative correlations with most subscales of the CS-PFP-10 (not upper body strength, Table 39). Clearly, for ball circles to the right the less variable the temporal pattern, the higher the perceived independence during activities of daily living. This is interesting when one considers the non-significant positive correlations between the same variables for ball circles to the left (Table 38).

Table 35. Correlations between kinematic parameters and functional variables for ankle sways.

Ankle Sways		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=34)	**YAW** (n=34)	**ROLL** (n=34)	**PITCH** (n=34)	**YAW** (n=34)	**ROLL** (n=34)	**mean** (n=33)	**S.D.** (n=33)
VADL	**FXAL**	-0.15	-0.01	-0.10	-0.10	-0.05	-0.15	-0.03	0.13
	AM	-0.19	-0.13	0.01	-0.13	-0.10	-0.16	-0.04	0.28
	INS	-0.18	-0.25	-0.15	-0.02	0.06	-0.12	0.14	**0.44**
	TOT	-0.23	-0.17	-0.01	-0.15	-0.09	-0.15	0.01	**0.38**
DHI	**PHYS**	-0.24	-0.14	-0.02	-0.14	0.08	0.18	-0.01	0.32
	FXAL	-0.20	-0.14	0.10	-0.16	-0.08	-0.14	0.02	**0.42**
	EMOT	-0.23	-0.15	0.06	-0.08	-0.04	-0.10	0.01	**0.44**
	TOT	-0.23	-0.15	0.05	-0.14	-0.07	-0.14	0.01	**0.41**
CS-PFP-10	**UPSTR**	0.16	0.06	-0.24	0.22	0.31	0.00	0.11	-0.27
	UPFLX	**0.56**	0.31	-0.41	0.51	0.32	0.31	0.28	-0.12
	LOSTR	0.17	0.09	-0.20	0.26	0.21	0.04	0.30	-0.01
	BC	0.23	0.05	-0.14	0.26	0.12	0.03	0.24	0.02
	END	0.24	0.13	-0.18	0.28	0.15	0.09	0.25	0.02
	TOT	0.24	0.11	-0.21	0.29	0.19	0.08	0.24	-0.04

Abbreviations for functional data are the same as those described in Table 6. Bold text represents $p<0.05$. Correlation n of CS-PFP-10 and Head Excursion data was 20 for each parameter while correlation n of CS-PFP-10 and Timing data was 20 for each parameter.

Table 36. Correlations between kinematic parameters and functional variables for circle sways left.

Circle Sways Left		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=32)	**YAW** (n=32)	**ROLL** (n=18)	**PITCH** (n=32)	**YAW** (n=32)	**ROLL** (n=18)	**mean** (n=33)	**S.D.** (n=33)
VADL	**FXAL**	0.04	0.11	-0.36	0.34	**0.56**	-0.29	0.13	**0.58**
	AM	0.01	0.06	-0.12	0.14	0.25	-0.18	0.18	**0.62**
	INS	-0.07	-0.09	0.01	-0.06	-0.06	0.04	0.22	**0.53**
	TOT	-0.02	0.03	-0.22	0.12	0.26	-0.21	0.20	**0.62**
DHI	**PHYS**	-0.07	-0.05	-0.34	0.17	0.29	-0.30	0.15	**0.53**
	FXAL	-0.09	-0.05	-0.18	0.06	0.17	-0.20	0.14	**0.52**
	EMOT	-0.07	-0.07	-0.18	0.09	0.19	-0.16	0.12	**0.53**
	TOT	-0.08	-0.06	-0.24	0.11	0.22	-0.23	0.14	**0.54**
CS-PFP-10	**UPSTR**	0.32	0.32	0.36	0.27	0.21	0.30	0.03	-0.23
	UPFLX	0.36	0.36	0.36	0.35	0.34	0.33	-0.18	-0.22
	LOSTR	0.38	0.34	0.36	0.38	0.34	0.40	0.03	-0.31
	BC	0.44	0.35	0.45	0.37	0.24	0.48	-0.11	-0.44
	END	0.37	0.31	0.35	0.34	0.28	0.37	-0.08	-0.42
	TOT	0.40	0.35	0.40	0.36	0.29	0.41	-0.07	-0.39

Abbreviations for functional data are the same as those described in Table 6. Bold text represents $p<0.05$. Correlation n of CS-PFP-10 and Pitch/Yaw Head Excursion data was 19 for each parameter while correlation n of CS-PFP-10 and Roll Head Excursion data was 11 for each parameter. Correlation n of CS-PFP-10 and Timing data was 19 for each parameter.

For the gait with head movement exercise many significant correlative relationships existed between the step path characteristics and the functional assessments (Table 40). It is not surprising that gait time and step number demonstrated positive correlations with the DHI and VADL scales (excluding the VADL Instrumental subscale) and negative correlations with the CS-PFP-10,due to the fact that lower scores on the CS-PFP-10 indicates poorer performance, while lower scores on the DHI and VADL indicate better perceived performance. The negative correlations between the three subscales of the CS-PFP-10 (lower body strength, balance and coordination, and endurance) and step number and gait time only reached significance for the former. Therefore, as a subjects’ gait time and step number increased the perceived handicap and dependence increased, while functional performance during ADLs decreased only when step number increased. Cadence exhibited significant negative correlations with scales of the DHI and VADL and positive correlations with the three above-listed subscales of the CS-PFP-10. In this case a slower cadence during gait with head movements is related to increased perceived handicap and dependence and decreased daily function performance in tasks requiring lower body strength, balance and coordination, and endurance. Note similarities in step number and cadence which represent the number of steps and the number of steps per second, respectively.

Table 37. Correlations between kinematic parameters and functional variables for circle sways right.

Circle Sways Right		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=32)	**YAW** (n=32)	**ROLL** (n=25)	**PITCH** (n=32)	**YAW** (n=32)	**ROLL** (n=25)	**mean** (n=33)	**S.D.** (n=33)
VADL	**FXAL**	-0.26	0.00	0.08	-0.12	0.34	-0.15	0.24	**0.74**
	AM	-0.14	0.00	0.03	-0.12	0.16	-0.17	0.19	**0.57**
	INS	0.00	0.19	-0.32	0.02	0.19	-0.31	0.03	**0.37**
	TOT	-0.17	-0.01	-0.10	-0.11	0.21	-0.25	0.16	**0.59**
DHI	**PHYS**	-0.26	0.01	-0.19	-0.12	0.23	-0.27	0.14	**0.63**
	FXAL	-0.21	0.01	-0.08	-0.11	0.16	-0.21	0.10	**0.44**
	EMOT	-0.18	-0.10	-0.16	-0.08	0.10	-0.22	0.09	**0.54**
	TOT	-0.22	-0.02	-0.14	-0.11	0.17	-0.24	0.11	**0.54**
CS-PFP-10	**UPSTR**	0.29	0.20	-0.19	0.23	0.19	-0.10	-0.12	-0.08
	UPFLX	0.32	**0.55**	0.17	0.40	0.40	0.34	-0.06	0.01
	LOSTR	0.15	0.13	-0.15	0.19	0.15	-0.01	0.03	0.14
	BC	0.21	0.19	-0.22	0.12	0.01	-0.03	-0.10	-0.05
	END	0.15	0.18	-0.22	0.18	0.09	0.02	-0.05	0.05
	TOT	0.21	0.21	-0.19	0.20	0.12	0.01	-0.07	0.02

Abbreviations for functional data are the same as those described in Table 6. Bold text represents $p<0.05$. Correlation n of CS-PFP-10 and Pitch/Yaw Head Excursion data was 18 for each parameter while correlation n of CS-PFP-10 and Roll Head Excursion data was 15 for each parameter. Correlation n of CS-PFP-10 and Timing data was 19 for each parameter.

Table 38. Correlations between kinematic parameters and functional variables for ball circles left.

Ball Circles Left		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=34)	**YAW** (n=34)	**ROLL** (n=33)	**PITCH** (n=34)	**YAW** (n=34)	**ROLL** (n=33)	**mean** (n=33)	**S.D.** (n=33)
VADL	**FXAL**	-0.12	-0.01	-0.19	-0.22	-0.12	0.04	0.26	-0.11
	AM	-0.27	-0.26	-0.10	-0.25	-0.02	0.04	0.19	-0.08
	INS	-0.11	-0.17	-0.16	-0.05	0.15	-0.01	0.01	-0.07
	TOT	-0.23	-0.16	-0.18	-0.23	0.01	0.02	0.24	-0.10
DHI	**PHYS**	-0.13	-0.05	-0.22	-0.12	0.04	0.04	0.26	-0.06
	FXAL	-0.17	-0.17	-0.11	-0.22	0.00	0.03	0.26	-0.04
	EMOT	-0.10	-0.17	-0.17	-0.21	0.00	0.00	0.18	-0.08
	TOT	-0.14	-0.14	-0.17	-0.19	0.01	0.03	0.24	-0.06
CS-PFP-10	**UPSTR**	0.50	**0.48**	-0.22	0.41	0.29	-0.25	0.30	0.44
	UPFLX	0.25	0.06	-0.09	-0.14	-0.16	-0.23	-0.13	0.19
	LOSTR	**0.67**	**0.64**	-0.33	**0.49**	0.39	-0.18	0.23	0.35
	BC	**0.61**	**0.53**	-0.34	0.43	0.32	-0.19	0.08	0.34
	END	**0.64**	**0.56**	-0.34	0.43	0.31	-0.17	0.14	0.36
	TOT	**0.63**	**0.56**	-0.31	0.43	0.31	0.20	0.16	0.37

Abbreviations for functional data are the same as those described in Table 6. Bold text represents $p<0.05$. Correlation n of CS-PFP-10 and Head Excursion data was 20 for each parameter while correlation n of CS-PFP-10 and Timing data was 19 for each parameter.

Table 39. Correlations between kinematic parameters and functional variables for ball circles right.

Ball Circles Right		**Kinematic Parameters**							
		Head Excursions mean			**Head Excursions SD**			**Timing**	
		PITCH (n=31)	**YAW** (n=32)	**ROLL** (n=32)	**PITCH** (n=31)	**YAW** (n=32)	**ROLL** (n=32)	**mean** (n=31)	**S.D.** (n=31)
VADL	**FXAL**	-0.23	0.00	0.07	-0.22	0.26	-0.02	0.21	0.15
	AM	0.35	-0.31	-0.26	-0.20	0.16	-0.01	0.28	**0.35**
	INS	0.23	-0.14	-0.22	-0.15	-0.02	-0.10	0.11	0.23
	TOT	0.33	-0.25	-0.21	-0.21	0.15	-0.07	0.29	0.33
DHI	**PHYS**	0.26	-0.16	-0.08	-0.19	0.14	-0.06	0.33	0.26
	FXAL	0.36	-0.24	-0.19	-0.18	0.13	-0.06	**0.36**	**0.36**
	EMOT	0.19	-0.15	-0.20	-0.15	0.15	-0.04	0.22	0.19
	TOT	-0.20	-0.17	0.20	-0.18	0.15	-0.06	0.32	0.29
CS-PFP-10	**UPSTR**	**0.57**	0.33	-0.26	0.19	-0.18	-0.15	-0.06	-0.35
	UPFLX	0.24	0.10	0.22	0.25	-0.02	0.27	-0.45	**-0.83**
	LOSTR	**0.74**	**0.47**	-0.13	0.17	-0.15	0.06	-0.14	**-0.52**
	BC	**0.71**	0.34	-0.12	0.10	-0.25	0.06	-0.23	**-0.59**
	END	**0.72**	0.42	-0.09	0.16	-0.19	0.10	-0.20	**-0.60**
	TOT	**0.71**	0.40	-0.12	0.16	-0.20	0.06	-0.20	**-0.59**

Abbreviations for functional data are the same as those described in Table 6. Bold text represents $p<0.05$. Correlation n of CS-PFP-10 and Pitch Head Excursion data was 18 for each parameter while correlation n of CS-PFP-10 and Yaw/Roll Head Excursion data was 19 for each parameter. Correlation n of CS-PFP-10 and Timing data was 19 for each parameter.

Table 40. Correlations between kinematic parameters and functional variables for gait with head movement.

Gait with Head Movement (GHM)		**Step Path**		
		Gait Time (n=30)	**Steps Number** (n=30)	**Step Cadence** (n=30)
VADL	**FXAL**	**0.53**	**0.47**	**-0.53**
	AM	**0.54**	**0.56**	**-0.71**
	INS	0.25	0.24	**-0.52**
	TOT	**0.60**	**0.56**	**-0.69**
DHI	**PHYS**	**0.39**	**0.37**	**-0.57**
	FXAL	**0.48**	**0.46**	**-0.61**
	EMOT	**0.46**	**0.45**	**-0.57**
	TOT	**0.47**	**0.45**	**-0.61**
CS-PFP-10	**UPSTR**	-0.11	-0.27	0.42
	UPFLX	-0.05	-0.01	0.31
	LOSTR	-0.31	**-0.53**	**0.51**
	BC	-0.36	**-0.53**	**0.49**
	END	-0.37	**-0.55**	**0.51**
	TOT	-0.31	**-0.49**	**0.51**

Abbreviations for functional data are the same as those described in Table 6. Bold text represents $p<0.05$. Correlation n of CS-PFP-10 and Step Path was 19 for each parameter.

Summary

For exercises that involved head and body movements, an increase in head movement in the plane or planes required to complete the task was commonly associated with better actual functional performance. Head movement and/or head movement variability in inappropriate planes during exercises was often associated with decreased perceived and actual physical functional performance. Moreover, longer cycle times and/or greater variability of cycle times for several body exercises and horizontal head movements were associated with decreased perceived function. Lastly, increased step number and slower cadence during gait with head movement were associated with increased perceived handicap and dependence and lower actual physical function. Thus, perceived and actual functions have several links to the given kinematic parameters during performance of the VR exercises.

DISCUSSION

The overall purpose of this study was to evaluate the effects of unilateral vestibular disorders and age on functional performance of activities of daily living and the performance of 10 exercises used for in home vestibular rehabilitation. Perceived and actual functional abilities and kinematic variables were compared for young controls, old controls, and unilateral vestibular patients. The organization of the discussion mirrors that of the methods and results for continuity. Outcomes of functional measures, across and within groups, are discussed first, followed by aging and patient effects on exercise kinematics, and then relationships discovered between exercise kinematics and functional measures. The subdivisions of the ten exercises for the eye exercises, head and eye exercises, and whole body exercises remain in most cases to help with interpretation. Information on clinical applications, the study limitations, and future directions for research on vestibular rehabilitation complete this chapter.

Functional Measures

The group scores in Table 8 give insight to the perceived and actual functional abilities of the subjects studied. Group Y demonstrated no handicap on the DHI (DHI total = 0) and complete independence during all ADLs on the VADL. Group O followed with minimal handicap on the DHI, moderate to high independence on the VADL, and moderate to high physical function on the CS-PFP-10. Similar values for healthy older adults have been observed for the DHI (Enloe & Shields, 1997), VADL (Cohen et al, 2000), and CS-PFP-10 (Cress et al, 1996). Group P demonstrated the worst performance on all three measures with high levels of handicap on the DHI, high levels of dependence on the VADL, and low physical function on the CS-PFP-10. Similar mean subscale and total scores of patients on the DHI (Enloe & Shields, 1997) and VADL (Cohen & Kimball, 2000) have been observed, however CS-PFP-10 scores have not been determined previously in this population. Interestingly, mean total scores for patients in the present study were similar to those for people with Parkinson’s disease (Hearty, Schenkam, Kohrt, & Cress, 2007). Individual data in Tables 6 and 7 show that most individual older subjects and patients follow these trends. See Tables 6 and 7 for ranges of handicap, independence and physical function on DHI, VADL, and CS-PFP-10.

Across the Experimental Groups

Relationships between scores of the various functional assessments (DHI, VADL, and CS-PFP-10) offered insight to the relationship among measurements across our subjects. Although the DHI measures perceived handicap and the VADL measures perceived dependence during daily activities, all DHI and VADL scores were positively correlated across subjects (Table 9). These data imply that a decrease in one's perceived handicap is related to a decrease in their perceived dependence. This was expected, as Cohen suggested in her two studies in the development of (Cohen & Kimball, 2000) and assessment of (Cohen et al, 2000) the VADL, it is highly correlated with the DHI. Therefore, our study further emphasizes that both tools effectively measure similar aspects of the subjects' perception of their handicap and/or dependence.

While the correlative relationships were not as promising between the subjective and objective measures across subjects, strong positive correlations did exist between the DHI Functional and VADL Ambulation subscales and many of the subscales of the CS-PFP-10 (Tables 9 and 10). In these cases increased perceived handicap during functional activities and increased perceived dependence during ADLs requiring walking were associated with greater dependence during the actual performance of ADLs requiring upper body strength, lower body strength, balance and coordination, and endurance (subscales of CS-PFP-10). These data add to results which showed that decreased ataxia during locomotion was related to decreased perceived dependence in VADL Ambulation scores (Cohen & Kimball, 2004) and increased performance on the sit to stand test resulted in decreased handicap on the DHI (Meretta et al, 2007) for patients with vestibular deficits after rehabilitation. In each case objective performance measures improved along with the subjective reports. These findings at first seem to contradict those from multiple studies which have demonstrated that while improved balance determined via computerized dynamic posturography occurs along with decreased handicap on the DHI, no correlations between the objective balance measures and subjective DHI scores exist (Perez et al, 2006; Badke et al, 2005). Rather than showing contradictory findings, together these data show that perceived handicap and actual sensory-integrated balance abilities are not associated, while better perceived ambulation and reductions in perceived handicap are associated with better upper and lower body strength, balance and coordination, and endurance that occur during performance of various ADLs.

Within the Experimental Groups

Within groups analyses offer insight to specific group contributions for the across group analyses. Similar to the across group analyses significant positive correlative relationships between the total DHI and VADL scores existed for O and P groups. These data again support previous findings of good correlation between VADL and DHI scores (Cohen et al, 2000). The present findings do not support such correlations with all the subscales of these measures. Inspection of the individual data points offer insight to these differences and suggest that within group homogeneity is at least partially to blame for the non-significant findings within groups O and P. Data for the DHI Physical and VADL Ambulation for all groups are plotted in Figure 1. Linear trend lines for all subjects (bold) and subjects in the O (dashed) and P (dotted) groups are shown and reveal that it is the heterogeneity across groups that drive the significant trend between these two measures in those analyses. This plot is representative of similar occurrences among subscale correlations within and across subjects.

Within group analyses also offered insight to specific group contributions for objective and subjective correlations across groups. The major comparisons of interest were between the VADL Ambulation, the DHI Functional and several of the CS-PFP-10 subscales. Like the subjective scale correlations, there were non-significant within group correlations that were significant for analyses across groups (e.g. compare VADL AMB and CS-PFP-10 UPSTR in Tables 10, 12, 14). Figure 2 shows that group homogeneity again contributes to these differences from across group analyses, but we cannot

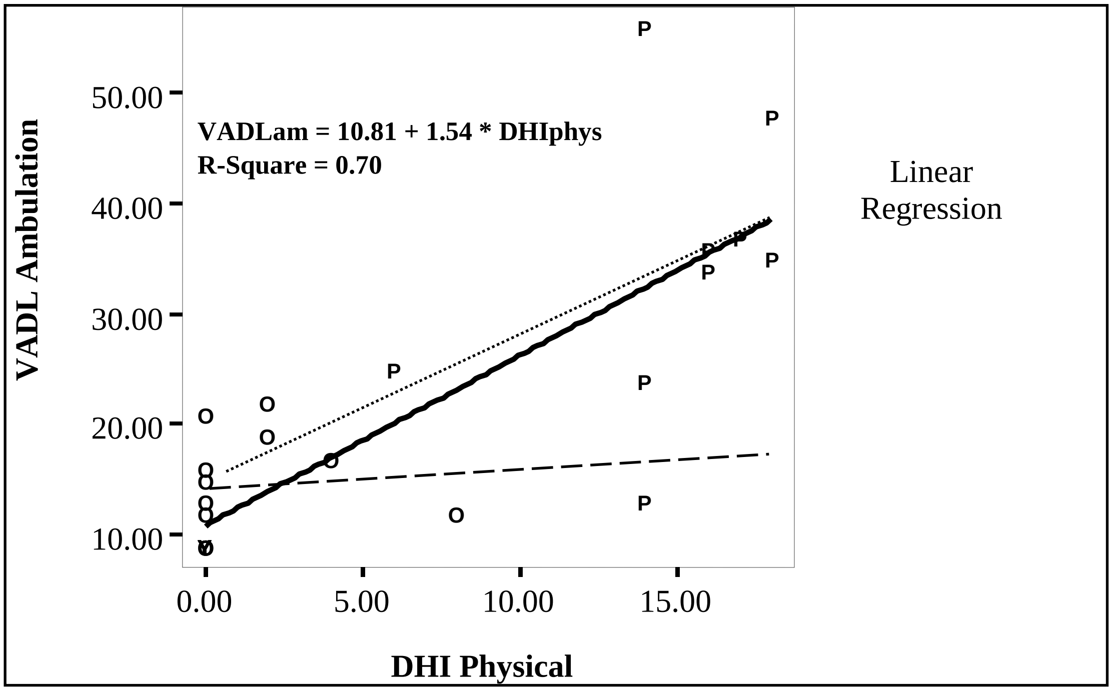

Figure 1. DHI Physical (DHIphys) and VADL Ambulation (VADLam) across groups. VADL Ambulation scores are plotted against scores for DHI Physical for all subjects and labeled by group: Y, O, and P. The associated linear trend line (bold) and its equation determined from the regression are provided. Linear trend lines for groups O (dashed) and P (dotted) are also shown.

rule out low subject numbers, thus inadequate power for the non-significant findings, especially when one considers that p-values were close to significance for with group outcomes (Group O, p = 0.07 and Group P, p = 0.12). In other instances the significant across group correlations seemed to be driven by one group. This can be clearly seen in Figure 3, which displays the correlations between DHI Functional and the upper body strength of CS-PFP-10. Note that the significant negative correlation which exists across groups (r = -0.69) is also identified for group P (r = -0.77), while the correlation between these measures for group O is not significant (r = 0.07). In a similar manner, data from group O drove the significant correlations between VADL Ambulation and CS-PFP-10 lower body strength, balance and coordination, endurance (data not shown, r-values in Table 8). With relatively large absolute r-values, larger patient numbers may have shown significant correlations for these measures.

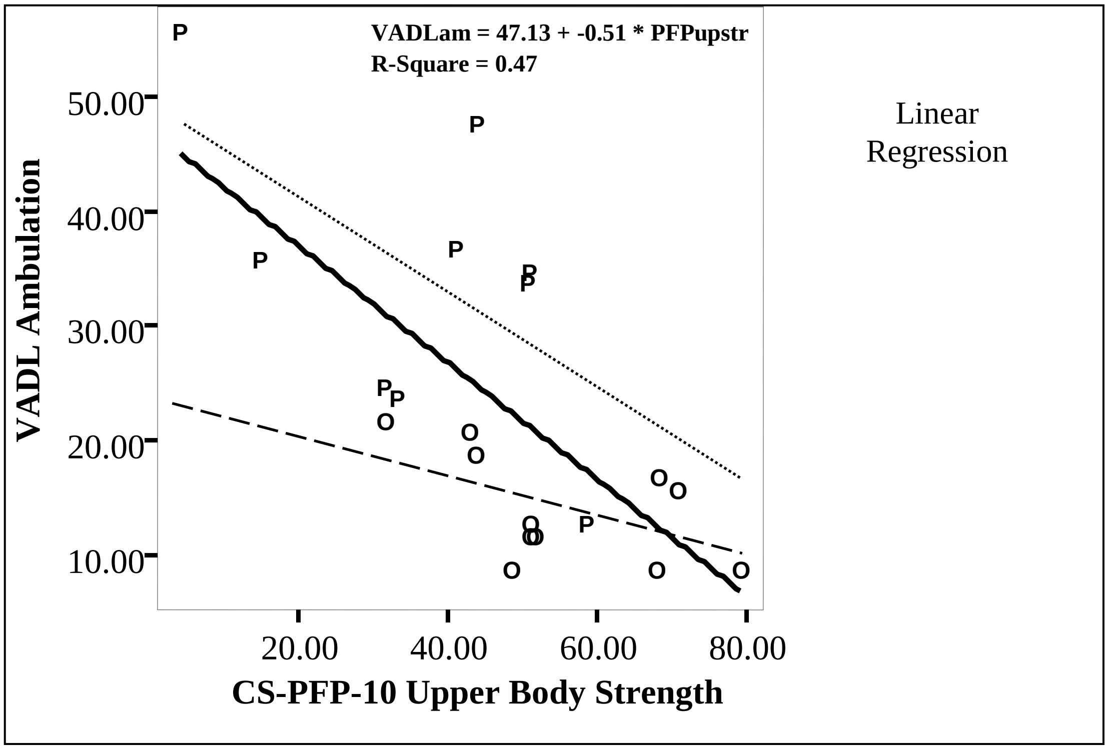

Figure 2. VADL Ambulation (VADLam) and CS-PFP-10 Upper Body Strength (PFPupstr) across groups O and P. CS-PFP-10 Upper Body Strength score are plotted against VADL Ambulation scores for each subject and labeled by group: O and P. The associated linear trend line (bold) and its equation determined from the regression are provided. Linear trend lines for groups O (dashed) and P (dotted) are also shown.

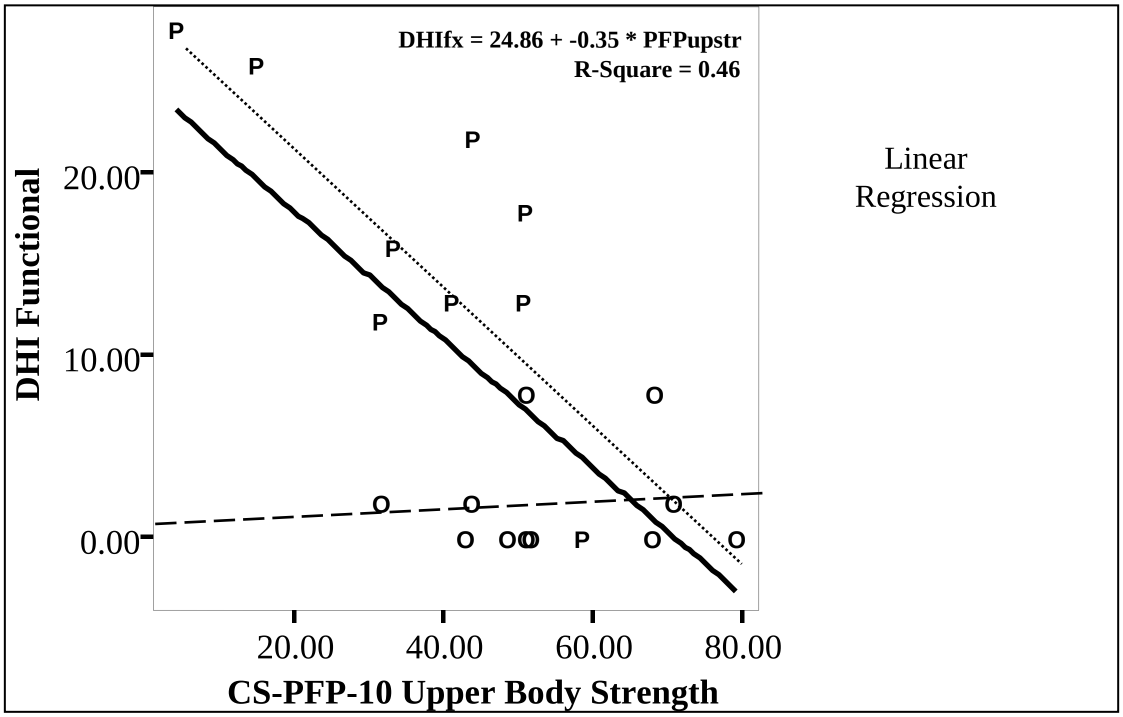

Figure 3. DHI Functional (DHIfx) and CS-PFP-10 Upper Body Strength (PFPupstr) across groups O and P. CS-PFP-10 Upper Body Strength score are plotted against DHI Functional scores for each subjects and labeled by group: O and P. The associated linear trend line (bold) and its equation determined from the regression are provided. Linear trend lines for groups O (dashed) and P (dotted) are also shown.

Exercise Kinematics

Kinematic strategies of body movements used by patients with chronic vestibulopathy and no history of vestibular rehabilitation were compared to young and older control subjects with no neurological deficits to offer insight to movement differences among groups. Results of kinematic performance across groups revealed that when the goal of the exercise was to keep the head still within the environment with eye exercises, the oldest subjects (group O) moved their heads with greatest excursions. For exercises where the goal included head movement, there were several cases where the youngest subjects moved their heads the most in a given plane (i.e. Yaw excursions for focusing with head turns, Table 17; Roll excursions for head circles, Tables 18 and 19; horizontal head movements, Table 20; and targets, Table 21). Interestingly, in the body exercises, where the head and body movements were to be similar (ankle and circle sways, Tables 22-24), the oldest subjects had the greatest head movements, while the youngest subjects revealed the greatest Yaw excursions during the ball circles exercises (Tables 25 and 26), where the head was to move more than the body. The patient effects on kinematics seemed limited to certain exercises, which are discussed in detail below. In general, the young controls performed each exercise with a faster pace and less variability than the other two groups, however only a few significant results identified smaller temporal values for the Y group. Interpretations of said results will be grouped into sections of eye, head and eye, and whole body exercises followed by overall timing data.

Eye Exercises

Since the goal of the eye exercises is to keep the head still, we expected little head movement in the pitch, yaw, or roll planes during the visual tracking and saccades exercises. The older subjects demonstrated the greatest head excursions and variability for both eye exercises, with largest excursions in visual tracking (see Table 15). In this case O and P groups produced more than twice the head movement in the yaw plane compared to group Y. It appears that regardless of vestibular function it is more difficult for older subjects to avoid moving their head in the yaw plane along with hand movement used to move the playing card and associated eye movements in this plane. Although the older adults performed greater Roll excursion during visual tracking compared to groups Y and P, the mean radian difference was only 0.02 (approximately 1^{o}), which likely has no true meaningful significance. The patients and young controls were also able to limit their head movement more than the older controls during the saccade exercise (see excursions, Table 16). One can assume that while the young subjects were performing the exercises correctly with good head stability, the patients likely adopted a head stabilization strategy to simply avoid head movement, as described in previous studies (Cromwell et al, 2004; Cohen, 2004). This is achieved through co-contraction of the sternocleidomastoid muscles of the neck (Cohen, 2004).

The question remains of why the older adults have trouble stabilizing their heads during these exercises. One possibility is that subjects in group O performed the task differently. For example, the need for greater eye excursions to complete the exercises may have induced greater head movement. If this were true, group O and P subjects could have moved the card for visual tracking further than group Y and that group O may have held the cards for saccades at a great distance apart. However, based on the mean wrist length, or mean distance between position of wrist markers, and wrist length variability data, there were no differences in wrist length between each of the three subject groups (see Table 41). Therefore, the very nature of the task, rapid repositioning of the eyes onto the playing cards, may have encouraged the healthy older controls to move their head slightly to obtain better gaze stabilization on the targets.

Table 41. Descriptive statistics and group differences for wrist length and wrist length variability during the saccades exercise.

Saccades	**Young**		**Old**		**Patients**		**One-Way ANOVAs**		
	mean	**(n)**	**mean**	**(n)**	**mean**	**(n)**	**Y vs O**	**Y vs P**	**O vs P**
Wrist Length	400.20	13	438.85	11	431.68	4	0.71	0.89	0.99
Wrist Length Variability	.14	13	.17	11	1.39	4	0.10	**.05**	.06

Wrist length means are in millimeters. Number of data points used for analyses is (n). Bold text represents significant effects (p<0.05).

Head and Eye Exercises

Previous researchers have suggested that increased head movements and increased movement in the visual surroundings are what is most appropriate for successful vestibular rehabilitation (Chang & Hain, 2008; Cohen & Kimball, 2004; Gottshall et al, 2006). This makes the head and eye exercises of particular interest in this study. For the focusing with head turns exercise, effects of age in the yaw plane was such that group Y had the greatest excursions with the least variability (see yaw excursion and SD, Table 15). This is slightly different from the head circle exercises where the age effects revealed that group Y had the greatest excursion in the roll plane, while the P and O groups had larger mean excursion values in the yaw plane, however these were only significant in the right direction. A pictorial display of these findings is plotted in Figure 4, showing that while the young subjects were rotating the head in a circular fashion (Fig. 4A), the older subjects' (O and P groups) head rotations were less circular (Fig. 4B) and in many cases more oval (Fig. 4C). Although group P reported increased symptoms of dizziness during these exercises, patient effects were not identified. There is one obvious possibility related to the above outcomes. The decreased head excursions in the necessary plane of the task are explained by the decreased head and neck mobility demonstrated with aging (Paquette et al, 2006). This point is emphasized by the data that show age-related excursion effects within the patients (see Yaw excursions, Table 19 and Roll excursions, Tables 18 and 19).

Patient effects were quite evident for the horizontal head movements exercise. Group P performed the task with increased pitch and less roll excursions than controls (see Table 20). Greater mean Yaw SD and Pitch SD were also identified for group P compared to groups O and Y, however between group comparisons only identified one significant difference which was for the yaw plane variability of the Y and P groups. The fact that patients in the present study decreased roll plane excursions compared to controls contrasts the increased roll for vestibular patients over normal subjects during walking (Mamoto et al, 2002). The present pitch results also differ from those reports of bilateral patients' head movements during over-ground walking, walking in place, running in place, and hopping (Pozzo et al, 1991) and those of caloric induced nystagmus in normal, young adults during walking in place and treadmill walking (Kubo et al, 1997). In contrast the pitch plane findings of the current study agree with those reports of unilateral and bilateral patients' head movements during treadmill walking with gaze stabilization (Mamoto et al, 2002). In each comparison study the patients or simulated patients (those with caloric-induced nystagmus) walked slower than controls, however it was only in the latter study that patients pitch head movements differed from controls in that they moved the head through larger pitch excursions, similar to the patients in the present study. In these two cases the subjects had a target for continuous (Mamoto et al, 2002) or periodic (present study) gaze stabilization, thus subjects could not choose a comfortable location for their gaze. Since this comfortable location of gaze varied

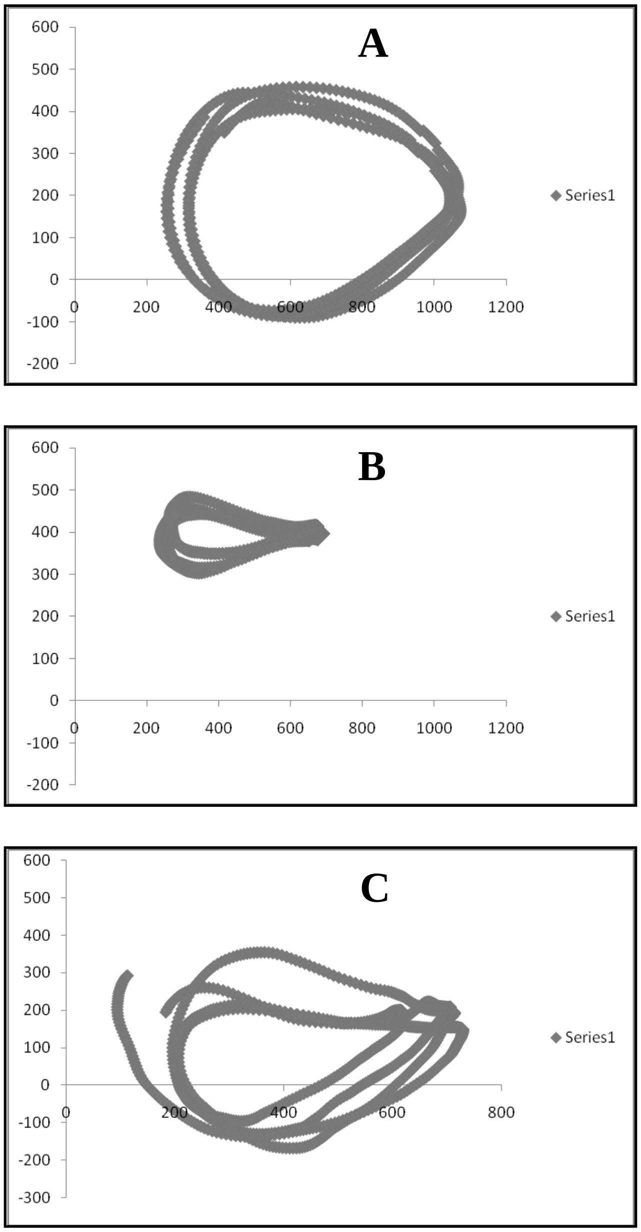

Figure 4. The top head marker of one subject from the Y group (A), O group (B), and P group (C) during the head circles to the left exercise is shown for the 5 cycles used in analyses. x- and y-axes correspond to actual x- and y-coordinates (mm).

greatly for those patients with bilateral deficits whose gaze was not restricted in this regard (Pozzo et al, 1991), forced gaze stabilization contributes to the greater movement and variability in the pitch direction. Another explanation for the differences in head excursions observed is based on the suggestions that there is no consistent pattern of head movement in bilateral patients during walking (Patten et al, 2003) and that visually sensitive subjects, like those with vestibular deficits (Chang &

Hain, 2008), produce increased head movements relative to controls in planes orthogonal to head motion due to various perturbations (Keshner & Dhaher, 2008). It is likely that the patients in the current study had this control difficulty in the pitch plane, an orthogonal plane to the primary yaw rotation required to perform this exercise.

So what explains the differences across head and eye exercises? Remember that age effects were determined for the focusing with head turns (Table 17) and head circles (Tables 18 and 19) exercises, while patient effects were determined for the horizontal head movements (Table 20) and targets (Table 21) exercises. Although patient effects were not explicit in the targets exercise, the trend in the means follows that of horizontal head movements (compare larger mean pitch excursions and smaller mean roll excursions for patients compared to controls in Table 21). There is one major characteristic of the exercises that can account for these differences. Subjects self-selected the range of head motion in the exercises influenced by age, whereas the yaw head motion was externally driven for the horizontal head movement and target exercises. The more extreme yaw motion for the latter exercises is clear when one considers that patients moved their heads through yaw excursions less than 1.2 radians (70^o) for focusing with head turns and head circles, while this movement increased to greater than 1.7 radians ($\sim100^o$) for horizontal head movement and target exercises. Larger head excursions required in the latter exercises were obtained due to the requirement that subjects had to view externally placed visual markers to their left and right sides. Regardless of age or patient effects on different exercises, results of the present study suggest that certain exercises, like those that use visual cues, promote greater range of head motion. Such exercises are of particular interest to this population as previous studies suggest that promoting greater head and eye movements during vestibular rehabilitation are keys for success (Cohen & Kimball, 2004; Chang & Hain, 2008; Gottshall et al, 2006). In addition, exercises facilitating head and eye movements lead to decreased gait ataxia, even without the incorporation of whole body exercises into the VR protocol (Cohen & Kimball, 2004), and leads to increased range of head motion and faster head turns during everyday tasks by encouraging the patient to release the co-contraction of the sternocleidomastoid muscle (Cohen, 2004).

Body Exercises

Much like the eye exercises, group O moved their heads more than groups Y and P during ankle sways and circle sways exercises, where a stationary head relative to the trunk is required. These results seem to parallel those for postural strategies used for older adults. In response to perturbations young control subjects use what is referred to as an ankle strategy to maintain upright stance, while older control subjects use what is referred to as a hip strategy (Hatzitaki, Amiridis, & Arabatzi, 2005; Lee, Zavarei, Evans, Lelas, Riley & Kerrigan, 2005). In this case, the young healthy adults produce movements primarily at the ankle joint rather than the hip joint to maintain stance, while the opposite occurs with the older healthy adult. Such a strategy would cause greater movement of the upper body and head, similar to that seen in the current study. Although this cannot be verified due to marker loss in the current study, visual inspection of the markers available at different times during each performance suggest that this is a reasonable explanation, especially since the hip strategy has been well-established for older adults (Hatzitaki et al, 2005; Lee et al, 2005). As stated previously, it is reasonable to postulate that while the young subjects performed the exercises correctly with good head-on-trunk stability, the patients adopted a head stabilization strategy to simply limit head movement, thus dizziness (Cromwell et al, 2004; Cohen, 2004). This would explain why group P did not move to extremes like group O and they commonly produced head kinematics similar to young controls.

Similar to the head and eye exercises, group Y performed greater head excursions compared to the remaining two groups during the ball circles exercise, particularly in the yaw plane. Again one clear possibility exists in relation to the effects of age for this exercise. The decreased Yaw and sometimes Pitch excursions demonstrated by the older subjects (groups O and P) can be explained by the limitations of head and body range of motion demonstrated with aging (Paquette et al, 2006). This idea is further exemplified by an age-related excursion effect within the patients, at least for ball circles right (see Yaw excursions, Tables 25 and 26).

Unlike the first three body exercises, gait with head movement demonstrated significant patient effects for gait time, step number, step cadence, number of imbalances, need for support, and veering (see Table 27). Analogous to results described in previous studies (Pozzo et al, 2006; Cromwell et al, 2004; Perring & Summers, 2007; Paquet et al, 2006), our patients demonstrated the largest step numbers within a given distance and the slowest cadence. Group Y demonstrated the fastest gait and step cadence with the smallest number of steps, while group O's number of steps and step cadence was between the other groups. Data shown in Table 27 further support the fast to slow performance and the few to more step numbers for the Y, O, and P groups. The fact that group O was not as fast as and produced more steps than group Y is not surprising as older adults commonly produce slower stepping cadence and more steps in a given distance than young adults during walking gait with no head turns (Steffen, Hacker, & Molliner, 2002). Moreover, the present veering results complement those of a previous study on the effects of fast head turns on the standing and walking performance of unilateral vestibular patients (Paquet et al, 2006). In both cases side of vestibular lesion had no observable effect on the direction that the patient veers during a locomotor task. In fact, in the present study, most patients had the tendency to veer toward the direction of the initial yaw head turn of the gait with head movement task.

Timing

Few timing differences existed between all three groups during eye, head and eye, and body exercises. When significant differences did exist, group Y demonstrated the fastest timing means and/or least timing variability during the eye exercises (see Tables 15 and 16) and head and eye exercises (see Tables 17-21), compared to groups O and P. For the eye exercises, we expected this based on previous research about aging and oculomotor tasks (Baloh & Honrubia, 1990; Lopez, Baloh, & Honrubia, 1997).

Older adults, regardless of the presence of a vestibular lesion, generally perform visual tracking and saccades with slower latencies than younger adults during the oculomotor subtests of electro-nystagmography and video-nystagmography (Baloh & Honrubia, 1990; Lopez et al, 1997). Temporal findings for the head and eye exercises are also consistent with previous research. In addition to the age-related slowing for head movements (Paquette et al, 2006), vestibular deficient patients perform slower head movements than age-matched controls with no neurological dysfunction (Paquet et al, 2006; Paquette et al, 2006; Cohen, 2004). These researchers suggest that patients commonly adopt a strategy of co-contracting the sternocleidomastoid muscles on both sides of the neck which is thought to reduce range of motion of the head by reducing vertigo. This reduction in head movement in turn leads to slower head movements (Cohen, 2004). Note that no group differences were expected, or identified, in timing mean for horizontal head movements and targets exercises because these movements were externally paced with verbal cues from the examiner. Age-related slowing and/or greater temporal variability was expected for the body exercises, as such slowing is common in the performance of different whole body movements (Steffan et al, 2002). The alterations in performances of the ankle and circle sways exercises seem to have limited such differences across groups. The greater yaw excursions performed by group Y during the ball circles exercises (Tables 25 and 26) also explains the temporal similarities across subject groups for this exercise. In contrast, the faster gait time for the Y group during the gait with head movement exercise compared to groups O and P were evident (Table 27). These data reflect the well-known age-related slowing in gait (Steffan et al, 2002; Paquette et al, 2006; Paquet et al, 2006).

Exercise Kinematics and Functional Measures

Relationships between functional measures and kinematic variables obtained during exercise performance were investigated to help better understand possible control strategies used by the three subject groups and offer insight to the advancement of vestibular rehabilitation. Some exercises resulted in similar associations for kinematic measurements with actual and perceived functions (see Table 42). Decreases in temporal variability and step number and increases in step cadence caused increases in actual and perceived function. Other kinematic measurements that increased perceived and actual function were not always the same. Decreases in temporal means, head excursion variability, and Pitch and Yaw excursions and increases in Roll excursions were associated with increases in perceived function. Increases in head excursions and variability of head excursions were often associated with increases in actual function; however, for the targets exercise, decreases in excursion variability were associated with increases in function. The differences in perceived and actual function are not linked to the different types of exercises as one might initially assume, rather they can be explained by the groups compared for determining these associations. Since young controls did not perform the objective functional measurements (CS-PFP-10), they were not included in these comparisons. For this reason we do not separate this section into the three types of exercises as done previously. Instead comparisons are separated for perceived measures first, followed by those for actual functional measures.

Table 42. General trends of correlative relationships between exercise kinematics and perceived and actual functional measures.

	Increase in Perceived Function	**Increase in Actual Function**
Pitch Excursion	↓ FHT, HHM, Targ	↑ HCL, HCR, AS, BCL,BCR
Yaw Excursion	↓ VT	↑ FHT, HCL, HCR, CSR, BCL, BCR
Roll Excursion	↑ FHT, HHM	↑ FHT, HHM, HCR
Pitch SD	↓ FHT, HHM, Targ	↑ HCL, BCL
Yaw SD	↓ HHM, CSL	↑ VT ↓ Targ
Roll SD	NS	↑ SAC
Timing Mean	↓ HCL, BCR	NS
Timing SD	↓ HCL, AS, CSL, CSR, BCR	↓ VT, FHT, BCR
Gait Time	NS	NS
Step Number	↓ Gait	↓ Gait
Step cadence	↑ Gait	↑ Gait

Increase in perceived (left column) and actual (right column) function were associated with an increase, decrease, or no significant change (NS) for each kinematic measure for at least one exercise. Findings summarize the data from Tables 28-40.

Perceived Function

Significant associations observed in the correlations between exercise kinematics and perceived function, as indicated by the DHI and VADL, were identified. Previous results also showed that subjects in groups O and P were the only ones where some level of dependence and handicap existed, which would drive any significant associations. With the highest mean VADL and DHI values observed in the patients (Table 8) and the greatest patient effects observed for the horizontal head movement (Table 20) and gait with head movements (Table 27) exercises, it is not surprising that significant findings between the kinematic measurements from these exercises primarily correlated with perceived functional scores. While the horizontal head movements exercise revealed only patient effects, the gait with head movement exercise revealed patient and age effects in the regression analyses. Most of the remaining significant correlations between kinematic measures and scores for perceived function were observed with exercises where age effects were identified in the regressions. Together, these findings suggest that kinematic associations with increases in perceived function paralleled the aging and patient results from regression analyses on kinematic variables.

There is little research on the movement kinematics and perceived function in the vestibular population. One study revealed a significant association between the decreased time to complete a repetitive head movement task (i.e., moving small beanbags from one basket to another as rapidly as possible while seated in a chair) and increased independence in vestibular patients’ total VADL score after vestibular rehabilitation (Cohen 2004). In another retrospective rehab study, as vestibular patients decreased their time on the five times sit to stand test, they improved their DHI score (Meretta et al 2006). Findings from these studies resemble the current findings where decreased timing means were linked to increased perceived function (Table 42), regardless of the fact that patients in the current study did not receive rehabilitation. Results of a gait study revealed no significant correlation between patients’ perceived vertigo symptoms and their stride time variability (Perring & Summers, 2007). In contrast, in the current study decreased timing variability was associated with increased perceived function. These data suggest that perceived vertigo is not the same as perceived handicap or dependence and account for study differences.

Actual Function

Significant associations observed in the correlations between exercise kinematics and actual function, as indicated by the CS-PFP-10, were identified for subjects in the O and P groups. Subjects in group O revealed lower mean scores for different scales of the CS-PFP-10 (Table 6), suggesting that as a group the older controls had greater functional abilities used for activities of daily living. These findings support those of previous studies, which indicate patient dysfunction compared to healthy controls as indicated by objective functional measures of posturography (Meretta et al, 2006; Cohen & Kimball, 2004; Badket et al, 2005; Perez et al, 2006), gait (Cromwell et al, 2004; Perring & Summer, 2007; Paquet et al, 2006; Paqeutte et al, 2006; Pozzo et al), and various coordination tasks such as the sit to stand (Meretta et al, 2006). Several age effects in regression analyses of the current study revealed that healthy older adults often performed greater head excursions compared to patients. In the gait with head movement exercise the older adults also had fewer steps and faster cadence compared to patients. Therefore, the links between greater actual function and greater movement kinematics performed at a faster pace were expected. These data correspond nicely with those in the literature for rehabilitated vestibular patients. Researchers previously showed that decreased time on the five times sit to stand task was significantly associated with decreased gait speed, decreased Timed Up and Go score (the time to stand, walk around a cone 3 meters away, return, and sit) and decreased fall risk, as determined by an increase in the multiple components of complex gait (i.e. turning, stepping over obstacles, etc.), as assessed by the Dynamic Gait Index (Meretta et al, 2006). In addition, decreased stride time variability during gait demonstrated significant correlations with increased equilibrium scores of posturography and decreased fall risk of the Tinetti gait and balance assessment (Perring & Summers, 2007). Interestingly, the current correlation findings on older healthy controls and vestibular patients parallel the results for the rehabilitated vestibular patient population.

Surprisingly, the exercises with patient effects on head movement revealed few associations with actual function. One would expect that if the patients limited their head movement during the functional tasks of the CS-PFP-10 that it would have correlated well with the circle sway kinematics where the patients limited their head movement compared to healthy older controls. In contrast, one would expect that if the patients performed greater unwanted head movements in the tasks of the CS-PFP-10, like those observed for the horizontal head movement exercise, then more significant correlations would have been revealed. With no consistent outcomes for these associations it seems most likely that the unilateral vestibular patients are like those with bilateral lesions in that they reveal inconsistent head movements (Patten et al, 2003).

Conclusions

The overall purpose of this study was to evaluate the effects of a unilateral vestibular disorder by examining the correlations among actual and perceived functional measures, the kinematic measurement differences among young healthy adults, older healthy adults, and older adults with unilateral vestibular deficits, and the correlations between kinematic and functional measures. In older adults, better strength, balance, coordination, and endurance during activities of daily living were associated with better perceived ambulation and reduction in perceived functional handicap. Older adults had difficulties stabilizing their heads relative to the environment during eye exercises and moved their heads more when the exercise required head stabilization relative to the body, probably due to alterations in performance of the exercises. Patients, who were also older adults, were able to suppress some of these movements, likely to prevent dizziness. Both older groups often reduced their head movements and/or moved differently from the young when movements were self-selected. The young adults moved their heads more completely according to the exercise requirements when the movements were self-imposed and not externally driven by a visual cue. When patients were forced to make greater horizontal head movements with intermittent gaze stabilization, they also made greater head movements orthogonal to the plane of motion for seated exercises. These findings show that some patient differences are linked to declines of normal aging and not that of the disorder. In addition patients took more steps at a slower pace for the gait with head movement exercise. The group differences in exercise kinematics guided the correlations between kinematics and functional data, so that the subject differences in correlations between actual function and head excursion kinematics differed from those for perceived function and head excursion kinematics. These data add to the limited findings on associations between kinematic measurements and functional performances and are the first to show that relationships between these measures across healthy and vestibular patient groups.

Clinical Implications

In the clinic setting, providers are very aware of the suffering that vestibular patients experience from the disabling symptoms and the profound implications on their daily lives and activities. Too often, patients struggle to accept that the most efficient way to promote adaptation, decrease symptoms, and improve daily function is to increase head movement. Therefore, motivation and psychological support from family, friends, and their medical providers is paramount. The original aim of the present study, in terms of clinical implications, was to determine whether differences among groups would offer insight into the effectiveness of each of the ten vestibular rehabilitation exercises in terms of kinematic performance and daily function. The present study did in fact reveal that four of the ten VR exercises (horizontal head movements, circle sways to the left and right, and gait with head movement) demonstrated clear patient effects in performance kinematics. The targets exercise is also a potential candidate as it revealed similar trends to those of the horizontal head movements. A more efficient vestibular adaptation protocol with fewer exercises should lead to proper patient compliance, motivation, and quicker improvements in the patient’s daily life function.

Our results do not disagree with the literature on the important aspects of vestibular rehabilitation. The present study promotes a vestibular rehabilitation protocol encouraging increased head and eye movements, like those induced in horizontal head movements, targets, circle sways, and gait with head movement) which in turn will lead to a reduction in symptoms and improvement in daily function (Cohen & Kimball, 2004; Chang & Hain, 2008). The current findings also encourage the inclusion of whole body exercises, such as circle sways and gait with head movement, to promote fall prevention, increase VOR stability, and increase gait stability (Desmond, 2004). Last, our exclusion of eye exercises from a potential vestibular rehabilitation protocol may seem to contradict previous findings that visual tracking and saccadic eye movement tasks do play an important role in gaze stabilization (Herdman, 1997b; Kasai & Zee, 1978; Segal & Katsarkas, 1988; Leigh, Huebner, Gordon, 1994). However, eye exercises, particularly visual tracking, are actually deemed more appropriate for bilateral vestibular patients as they are in need of these compensatory eye movement strategies to aid with visual motor control when trying to maintain head stabilization in space (Herdman, 1998; Kasai & Zee, 1978; Segal & Katsarkas, 1988; Leigh et al, 1994). Therefore, including eye exercises into the therapy protocol for a unilateral vestibular patient may not be necessary, as recommended by the current study.

Limitations

While much information was discovered and noteworthy regarding the functional measures across and within groups, aging and patient effects of kinematic performance of the vestibular rehabilitation exercises, and the relationships between the exercise kinematics and functional measures, limitations in the present study exist. Due to the limited sample size, particularly of group P, and the nature of subjective data, there is a strong need for future research with a larger sample size. In addition, although comparing young and old controls subjects to unilateral vestibular patients has demonstrated unique relationships among the subjective and objective assessments across and within groups, our patient group was comprised of all older adults, possibly limiting the age comparisons within this group. Next, using a single examiner for exercise instruction in session III and data analyses of all three sessions may have promoted bias in the findings. Another obvious limitation of the present study is the loss of the data. This drastically limited analyses, including those variables which would have offered insight to whole body performances. Last, effects of the VR exercises for treatment effects were not studied, but could give insight to functional changes brought on by vestibular rehabilitation.

Future Directions

Although the findings in the present study offer insight for improvements VR protocols for unilateral vestibular patients, future research is necessary to continue to advance the field of vestibular rehabilitation. The following suggestions would have improved the findings of the current study. A larger sample size would improve the power of the findings. Use of more motion-analysis cameras to prevent the loss of data would provide additional whole body variables for analyses and insight to these movements, while adding to the power. Multiple examiners, one to teach the exercises and one to analyze the data, would help to decrease possible bias. There is a strong need for a similar study with a treatment group and a delayed treatment group that also addresses the above limitations. Comparisons of kinematic performance of VR exercises with two separate patient groups at the pre-VR and post-VR stages would help determine if post-VR outcomes are similar to age-matched control subjects. Areas also in need of investigation based on the findings of the present study are inclusion of exercises or treatments with a higher total destabilizing protocol (Chang & Hain, 2008), such as patients watching optokinetics for extended periods of times, virtual reality programs, and exercises with increased visual stimuli, increased head movements, and altered floor surfaces. These are relatively new protocols that have been determined effective for those with unilateral vestibular deficits. Last, although few correlations were discovered between the DHI Emotional subscale and other functional measures and exercise kinematics, several studies have discussed the need for the inclusion of psychological component. Possible factors to investigate include concomitant cognitive-behavioral therapy, utilizing questionnaires with more of an emotional component, such as the newly developed Vestibular Rehabilitation Benefit Questionnaire (Morris, Lutman, & Yardley, 2009), or taking into account the effects of self-efficacy and self-perception on subjective data.

All in all, continued advancement of vestibular rehabilitation is necessary. While ideas in research may look great on paper, the fact is the clinic setting is quite different. While objective measures, such as the CS-PFP-10, are helpful and give true ideas about a patient's daily life function, the possibility of this assessment being performed in the clinic are slim due to issues such as limited physical space, time allowed, and insurance reimbursement. In addition, multiple studies (Cromwell et al, 2004; Cohen, 2004) along with the present study have demonstrated the avoidance of head movement or improper head movement exhibited by unilateral vestibular patients. Patient compliance with a home VR exercise plan can be poor without the proper encouragement from the medical provider or therapist and support from family and friends. While clinician-directed vestibular rehabilitation may be ideal for patient outcomes, it may not be ideal for a patient's busy lifestyle or financial situation to have multiple therapy appointments with multiple insurance co-payments or office visit charges. Therefore, the most important clinical aims of future studies should focus on striving to create an at-home VR protocol that will most efficiently alleviate the patient's disabling symptoms of their vestibular disorder while improving their daily life function.

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APPENDIX A: CONSENT FORM

1. **Study Title:** A Comparison of Visual and Kinematic Strategies Used by Normal Subjects and Chronic Peripheral Vestibular Patients in Vestibular Rehabilitation Exercises

2. **Performance Sites:** St. James Place Continuing Care Retirement Community, and the Department of Communication Sciences and Disorders

3. **Contacts:**

Dr. Jan Hondzinski, Assistant Professor, Kinesiology;	Daytime Phone: 578-9144
Ms. Micah Klumpp, Research Fellow & Ph.D. Student	Daytime Phone: 578-2545

4. **Purpose of the Study:**
   The overall aim of the present study is to identify behavioral strategies of vestibular patients and aged-matched controls to determine whether vestibular exercises are appropriate for vestibular rehabilitation (i.e., the rehabilitation exercises encourage functional performance of everyday activities, thus functional independence).

5. **Subjects:**
   A. Inclusion Criteria

REQUIREMENTS	GROUP Y	GROUP 0	GROUP P
Hearing Sensitivity	Normal (pure tone average ≤ 25dBHL)	N/A	N/A
Tympanograms	Type A	Type A	Type A
Otoscopic Exam	Unremarkable	Unremarkable	Unremarkable
Ear Health History	Unremarkable	Unremarkable	History of unilateral or bilateral vestibular disorder and associated symptoms
Vertebral Artery & Cervicospinal	Negative results	Negative results	Negative results
Dix-Hallpike	Negative results	Negative results	Negative results
HFHS	Normal VOR gain (1.0) and/or no after-nystagmus	Possible reduced VOR gain and/or after-nystagmus	Possible reduced VOR gain and/or after-nystagmus
SOP	No abnormal postural sway	No abnormal postural sway	Possible abnormally increased postural sway
Calorics	Normal	Normal	Possible caloric weakness or directional preponderance (Appendix F)
Vestibular Rehabilitation	No history or experience	No history or experience	No history or experience

   B. Exclusion Criteria: Adults with signs or symptoms of heart disease such as chest pain or shortness of breath, or any adults taking medicines that affect the heart and blood vessels. Also excluded are patients taking anti-depressant or anti-anxiety medicines. In addition, people who have been hospitalized within the past 6 months will be excluded, as will people with pacemakers, a history of severe heart rhythm disturbances, or uncontrolled diabetes, high blood pressure, or kidney disease.

C. **Maximum number of subjects:** 40

6. **Study Procedures:**

As a participant in this study I will be asked to attend three sessions each lasting about 60-90 minutes.

Session 1: In the first session, I will complete three questionnaires and a case history on health history and inner ear function and balance. Then, the investigators will visually examine my ears and perform tests to assess my middle ear function and hearing sensitivity. Next, the investigators will place electrodes on my low forehead and neck muscles and will ask me lie down flat on table and lift and turn my head while I listen to a loud clicking sound. Then, the investigators will place electrodes on the outer corners of my eyelids and on my low forehead and will ask me to maneuver my head and/or body in specific positions so that they can assess vertebral artery function, cervicospinal function, function of my vestibular system via fast head shakes, function of my vestibular system in certain body position (in which I will lie down and let my head hang off of the table), function of eye muscles (by moving my eyes with a target on a screen), and vestibular function as I am lying flat on back, with my head turned to the right and then to the left. I will be asked to stand on either a hard floor surface or a foam cushion, with my eyes open or closed, and with my feet close together (one in front of the other) or far apart (about shoulder width) For these tests I will be wearing a safety harness and receive the assistance and support of two examiners if I become very unstable—about to fall. Last, I will be asked to lie down at a 30^o angle on an angled-examination table and close my eyes while the examiner places cold or warm air in my right or left ear for 60 seconds. I will then be asked to keep my closed for another 40 seconds, and later, open them and look at a target for about 30 seconds.

Session 2: In the second session I will be asked to perform several activities of daily living, such as normal walking, carrying a pot from one counter to another, climbing a flight of stairs, sweeping some debris off the floor, emptying a washer and dryer, and so on.

Session 3: In the third session, the investigators will place electrodes on the outer corners of my eyelids and on my low forehead and reflective body markers on the front and back of my head, shoulders, elbows, wrists, hips, knees, and ankles, They will then instruct me how to perform Saccades, Tracking, Targets, Head Turns, Head Circles, Focus with Head Turns, Ankle Sway, Circle Sway, and Ball Circle vestibular rehabilitation exercises. I will be allowed to practice each exercise five times with guidance from the examiner, and I will then perform each exercise three times. Last, the examiner will place a harnace on my waist to prevent a fall and will instruct me how to perform the last exercise: Gait with Head Movement. I will then walk along a line while I horizontally turn my head back and forth. The examiner will be recording my walking patterns on video.

Treatment: If I have a peripheral vestibular disorders diagnosed by either a physician or an audiologist, I may be asked to continue participating this study to undergo vestibular rehabilitation therapy. I will simply continue practicing the exercises I learned in session III two to three times a day for 90 days. The examiner will check on me every week to verify that I am feeling okay. At the end of the 90 days, I will return to the laboratory to repeat sessions I, II, and III.

7. **Benefits:** This study is of no direct benefit to me; however information gained during the tests has the potential to provide me with information about the health and function of my inner ears.

8. **Risks**: There are few risks associated with the procedures in this study.

   Session 1: There are no known risks associated with the middle ear and hearing tests. There is the slight possibility that I may, however, feel some slight discomfort, nausea and/or dizziness, during the pre-test screenings of my cervicospinal column, vertebral artery, and vestibular system. There is also a low risk that I may experience some nausea and/or dizziness during the rotational chair and caloric testing.

   Session 2: In the condition of the balance test with eyes closed and standing on a foam surface, there is a low risk of increased postural sway and an "about-to-fall" feeling. The physical function tests are associated with a very-low risk of adverse heart and blood vessel responses. These include unusually high heart rate and/or blood pressure, and in very rare instances, stroke, heart attack and death. Physical activity is also associated with risk of muscle strains, ligament sprains, and other bone and joint injuries or discomfort.

   Session 3 and Treatment: There is also a low risk that I may experience some nausea and/or dizziness during the vestibular rehabilitation exercises. If I presently have a vestibular disorder, this is expected.

9. **Measures taken to reduce risk:** All participant information will remain confidential, and while the data collected in this study may result in publication, no participant will be identified by name or any other personal identifier. Records will be kept in a locked file cabinet located in a room dedicated for research with access only to project investigators.

   Session 1: Dizziness and nausea will be prevented by having me fixate on a target to halt the sensation of motion, ice cold packs nearby to place on the top of my head and back of my neck, a chair to rest my foot on to make me feel more grounded, at least two examiners nearby to lightly press on head and shoulders to make me feel more grounded, and longer breaks if I need them. For the balance test with the foam surface, I will be wearing a safety harnace and will receive the support and assistance of at least two examiners to minimize the risks of increased sway and the feeling of falling. The risks associated with the caloric testing will be minimized through proper screening, and monitoring heart rate, blood pressure and feelings of nausea and dizziness. In addition, steps will be taken to prevent nausea and dizziness by having me fixate on target to halt the sensation of motion, ice cold packs nearby to place on the top of my head and back of my neck, a chair to rest my foot on to make me feel more grounded, at least two examiners nearby to lightly press on head and shoulders to make me feel more grounded, and longer breaks if I need them. Any indication of adverse responses will result in stopping the test.

   Session 2: Screening for the presence of serious cardiovascular and other diseases will minimize the risks associated with physical exertion. In addition the investigators will monitor heart rate blood pressure, and continually ask me to report how I am feeling during the test. Should any indication of adverse responses arise, the test will be stopped

Session 3: For the exercises, I will be wearing a safety harnace and will receive the support and assistance of at least two examiners to minimize the risks of increased sway and the feeling of falling. Any indication of adverse responses will result in stopping the test.

Treatment: I will need to make sure that I am supervised my another person away from the laboratory while I am performing the treatment exercises. Dizziness and nausea will be prevented by having me fixate on a target to halt the sensation of motion, ice cold packs nearby to place on the top of my head and back of my neck, a chair to rest my foot on to make me feel more grounded, someone nearby to lightly press on head and shoulders to make me feel more grounded, and longer breaks if I need them.

10. **Right to Refuse:** I understand that participation in this study is voluntary and that I may change my mind and withdraw from the study at any time without penalty or loss of any benefit to which I may otherwise be entitled.

11. **Privacy:** This study is confidential. All data collected will be kept confidential. While the results of the study may be published, I will not be identified by name or any other personal identifier.

HIPPA / CONFIDENTIALITY: Records that you give us permission to keep, and that identify you, will be kept confidential as required by law. Federal Privacy Regulations provide safeguards for privacy, security, and authorized access. Except when required by law, I will not be identified by name, social security number, address, telephone number, or any other direct personal identifier in records disclosed outside of Louisiana State University (LSU). For records outside of LSU, I will be assigned a unique code number.

12. **Compensation/Financial Information:** I understand that I will incur no financial costs as a result of participation in this study, nor will I be compensated for participation in this study. I also understand that any adverse responses that result in medical treatment are my financial responsibility. No form of compensation for medical treatment or for other damages (i.e., lost wages, time lost from work, etc.) is available from LSU A&M College, or St. James Place. In the event of injury or illness resulting from the research procedures in which you participate, you will be referred to a treatment facility. Medical treatment may be provided at your expense or at the expense of your health care insurer, which may or may not provide coverage. Community physicians and hospitals must provide medical treatment to which you are referred.

13. **Withdrawal:** As a participant in this study, I understand that I have the right to withdraw from any or all parts of this study at any time. I understand that I need only indicate to the investigator(s) verbally or in writing my decision regarding withdrawal.

14. **Removal:** As a participant in this study I also understand that the investigators may remove me from the study for any number of reasons, including, but not limited to, the detection of adverse responses, their appraisal of my health status, and technical difficulties in obtaining information during the testing session. I understand that if the investigators elect to remove me from the study they will provide me with the justification for doing so, and I will be given an opportunity to ask questions regarding my removal.

Signatory

1. Literate subjects: This study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. I may address questions regarding the study to Drs. Robert Wood (225/ 578-9142) and/or Jan Hondzinski (225/ 578-9144), in the department of Kinesiology at LSU. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Chairman, LSU Institutional Review Board, (225/ 578-8692). I agree to participate in the study described above and acknowledge the researchers' obligation to provide me with a copy of this consent form if signed by me.

Subject Signature Date

2. Illiterate subjects: The study subject has indicated to me that he/she is unable to read. I certify that I have read this consent form to the subject and explained that by completing the signature line above, the subject has agreed to participate.'

Signature of Reader Date

Signature of Investigator Date

APPENDIX B: AUDIOLOGY CASE HISTORY

Patient Name: ______________________________ Date: ____________________
Family Physician: ____________________________ Date of Birth: ______________

Do you have any of the following symptoms? Put an ‘x’ indicating YES or NO, and circle the ear involved.

YES NO

☐ ☐ Difficulty in hearing? Both ears? Right ear Left ear
When did this start? ____
Is it getting worse? ____
Was the decrease gradual or sudden? ____
☐ ☐ Dizziness, vertigo, dysequilibrium, and/or imbalance problems?
☐ ☐ Noise in your ears? Both ears Right ear Left ear
Describe the noise ____
☐ ☐ Does the noise change with dizziness? If so, how? __________________________
☐ ☐ Does anything stop the noise or make it better? If so, what? ____________________
☐ ☐ Fullness or stuffiness in your ears? Both ears Right ear Left ear
Does this change when you are dizzy? _______________________________________
☐ ☐ Pain in your ears? Both ears Right ear Left ear
☐ ☐ Discharge from your ears? Both ears Right ear Left ear
☐ ☐ Recent ear infection in your ears? Both ears Right ear Left ear

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Please put an ‘x’ indicating YES or NO and fill in the blank spaces.

YES NO

☐ ☐ Have you had your hearing tested?
If yes, when and what were the test results? ____________________________________
☐ ☐ Does your hearing seem to fluctuate?
☐ ☐ Is your hearing the same in both ears?
If no, which ear is your better ear? Right ear Left ear
☐ ☐ Family history of hearing loss?
If so, what relation and describe their hearing loss. ___________________________
☐ ☐ History of noise exposure in your employment (e.g. factory, military)?
If so, describe. ____
☐ ☐ History of noise exposure in recreational activities (e.g. hunting, woodworking, machinery)? If so, describe. ____
If so, are you right or left-handed? _______________________________________
☐ ☐ Have you worn hearing protection when exposed to loud noises?
☐ ☐ Have you been away from loud noises for 14 to 16 hours prior to today’s assessment?
☐ ☐ Do you have trouble hearing the television?
☐ ☐ Do you have trouble hearing at work?
☐ ☐ Do you have trouble hearing in groups/noise?
☐ ☐ Do you have difficulty understanding others?
☐ ☐ Do you use the telephone? If yes, which ear? Right ear Left ear
☐ ☐ Have you ever worn a hearing aid? Both ears Right ear Left ear
☐ ☐ Are you opposed to wearing a hearing aid?

Please put an ‘x’ indicating YES or NO and fill in the blank spaces.

YES NO

☐ ☐ Do you have any allergies? If yes, describe. ________________________________
☐ ☐ Have you had any trauma to your head, neck, or ears?
☐ ☐ If you received a head injury, were you unconscious?
☐ ☐ Are you currently being treated for any major medical conditions? If yes, what? __________
____
☐ ☐ Have you ever had a serious illness or disease? ______________________________
☐ ☐ Do you take any medications regularly (e.g. tranquilizers, oral contraceptives, barbiturates, antibiotics)? Please list. ____
____

☐ ☐ Do you have high or low blood pressure? ____________________________________
☐ ☐ Do you have diabetes, glaucoma, or peripheral neuropathy? __________________________
☐ ☐ Have you ever had a stroke, TIA, or kidney disease? ________________________________
☐ ☐ Have you ever had any back or neck problems? __________________________________
☐ ☐ Do you have a history of motion sickness and/or migraines?
☐ ☐ Do you or anyone in your family have a history of cardiovascular problems?

Do you experience any of the following sensations? Please read the entire list first. Then circle each symptom that describes your feelings most accurately.

Light headedness
Swimming sensation in your head
Blacking out
Loss of consciousness
Objects spinning around you
Sensation that you are spinning

Tendency to fall to the RIGHT
……………………… LEFT
……………………… FORWARD
……………………… BACKWARD
Loss of balance when walking … veering to the RIGHT
………………………………… veering to the LEFT

Headache
Nausea or vomiting
Pressure in the head

Please put an 'x' indicating YES or NO and fill in the blank spaces.

YES NO
☐ ☐ My dizziness is constant?
☐ ☐ ……………….in attacks? If yes, how often? ___________________________________
When did dizziness first occur? ____
Do you have any warning that the attack is about to start? __________________________
☐ ☐ Are you completely free of dizziness between attacks?
☐ ☐ Does dizziness occur only in certain positions?
☐ ☐ Do you have trouble walking in the dark?
☐ ☐ When you are dizzy, must you support yourself when standing?
☐ ☐ Do you know any possible cause of your dizziness? _______________________________
☐ ☐ Do you know of anything that will … stop your dizziness or make it better?
☐ ☐ ……………………………………... make your dizziness worse?
☐ ☐ …………………………………….. precipitate an attack?
☐ ☐ Were you exposed to any fumes, paints, etc., at the onset of dizziness?

Have you ever experienced any of the following symptoms? Put an 'x' indicating YES or NO, and circle if Constant or if in Episodes?

YES NO
☐ ☐ Blurred/double vision, blindness, or spots before the eyes? Constant Episodes
☐ ☐ Numbness of face or extremities? Constant Episodes
☐ ☐ Weakness and/or clumsiness in arms or legs? Constant Episodes
☐ ☐ Confusion or loss of consciousness? Constant Episodes
☐ ☐ Difficulty in swallowing? Constant Episodes
☐ ☐ Tingling around mouth? Constant Episodes

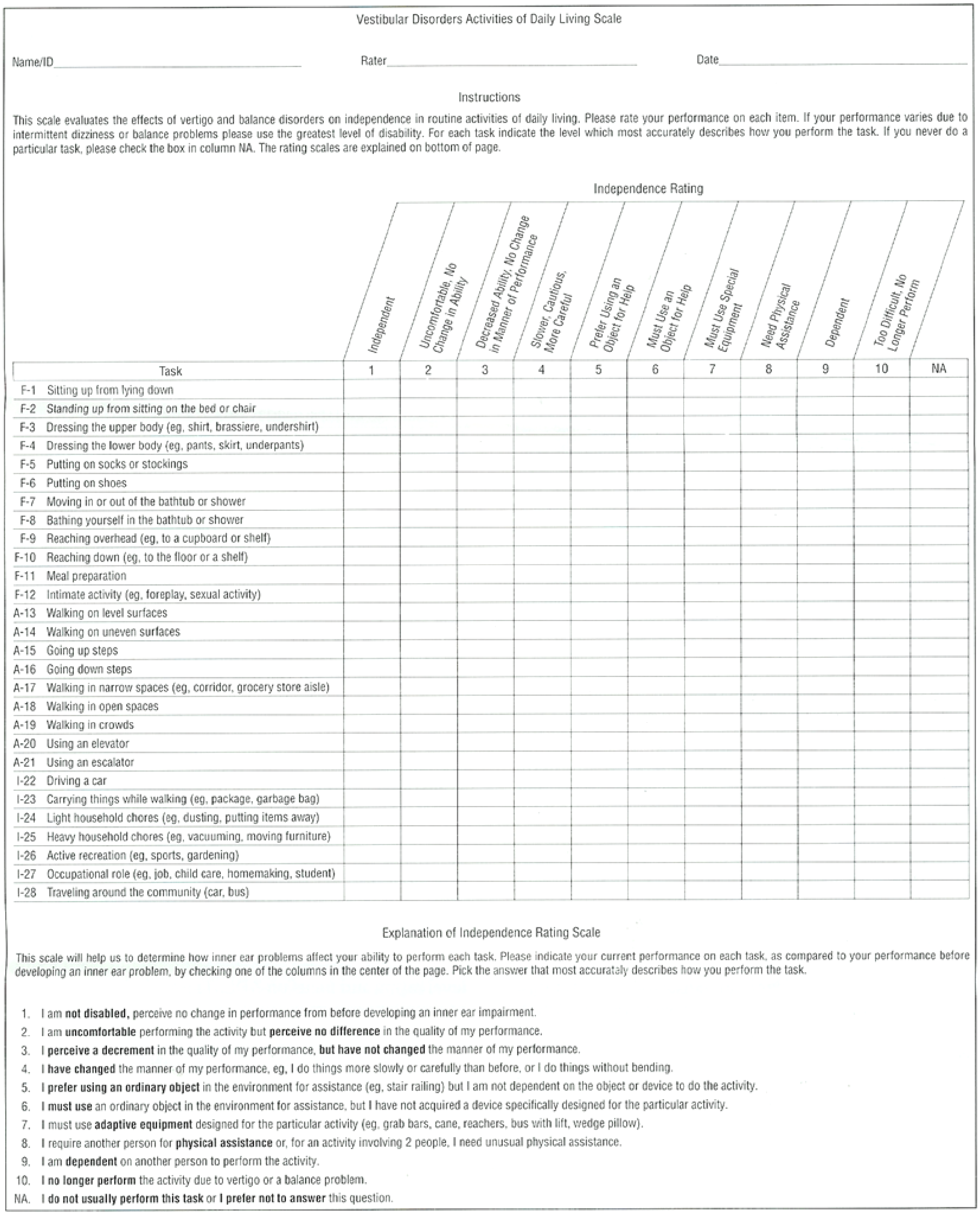
Please put an 'x' indicating YES or NO.

YES NO
☐ ☐ Do you get dizzy after exertion or overwork?
☐ ☐ Did you get new glasses recently?
☐ ☐ Do you tend to get upset easily?
☐ ☐ Do you get dizzy when you have not eaten for a long time?
☐ ☐ Is your dizziness connected with your menstrual period?
☐ ☐ Have you been under a lot of stress recently?

Please describe any other symptoms and feelings. ____
____

APPENDIX C: PERCEIVED AND ACTUAL FUNCTIONAL MEASURES

VESTIBULAR DISORDERS ACTIVITIES OF DAILY LIVING



Vestibular Disorders Activities of Daily Living Scale

Name/ID____________________ Rater____________________ Date____________________

Instructions

This scale evaluates the effects of vertigo and balance disorders on independence in routine activities of daily living. Please rate your performance on each item. If your performance varies due to intermittent dizziness or balance problems please use the greatest level of disability. For each task indicate the level which most accurately describes how you perform the task. If you never do a particular task, please check the box in column NA. The rating scales are explained on bottom of page.

		Independence Rating										
		Independent	Uncomfortable, No Change in Ability	Decreased Ability, No Change in Manner of Performance	Slower, Cautious, More Careful	Prefer Using an Object for Help	Must Use an Object for Help	Must Use Special Equipment	Need Physical Assistance	Dependent	Too Difficult, No Longer Perform	
	Task	1	2	3	4	5	6	7	8	9	10	NA
F-1	Sitting up from lying down											
F-2	Standing up from sitting on the bed or chair											
F-3	Dressing the upper body (eg, shirt, brassiere, undershirt)											
F-4	Dressing the lower body (eg, pants, skirt, underpants)											
F-5	Putting on socks or stockings											
F-6	Putting on shoes											
F-7	Moving in or out of the bathtub or shower											
F-8	Bathing yourself in the bathtub or shower											
F-9	Reaching overhead (eg, to a cupboard or shelf)											
F-10	Reaching down (eg, to the floor or a shelf)											
F-11	Meal preparation											
F-12	Intimate activity (eg, foreplay, sexual activity)											
A-13	Walking on level surfaces											
A-14	Walking on uneven surfaces											
A-15	Going up steps											
A-16	Going down steps											
A-17	Walking in narrow spaces (eg, corridor, grocery store aisle)											
A-18	Walking in open spaces											
A-19	Walking in crowds											
A-20	Using an elevator											
A-21	Using an escalator											
I-22	Driving a car											
I-23	Carrying things while walking (eg, package, garbage bag)											
I-24	Light household chores (eg, dusting, putting items away)											
I-25	Heavy household chores (eg, vacuuming, moving furniture)											
I-26	Active recreation (eg, sports, gardening)											
I-27	Occupational role (eg, job, child care, homemaking, student)											
I-28	Traveling around the community (car, bus)											

Explanation of Independence Rating Scale

This scale will help us to determine how inner ear problems affect your ability to perform each task. Please indicate your current performance on each task, as compared to your performance before developing an inner ear problem, by checking one of the columns in the center of the page. Pick the answer that most accurately describes how you perform the task.

1. I am **not disabled,** perceive no change in performance from before developing an inner ear impairment.
2. I am **uncomfortable** performing the activity but **perceive no difference** in the quality of my performance.
3. **I perceive a decrement** in the quality of my performance, **but have not changed** the manner of my performance.
4. **I have changed** the manner of my performance, eg, I do things more slowly or carefully than before, or I do things without bending.
5. **I prefer using an ordinary object** in the environment for assistance (eg, stair railing) but I am not dependent on the object or device to do the activity.
6. **I must use** an ordinary object in the environment for assistance, but I have not acquired a device specifically designed for the particular activity.
7. I must use **adaptive equipment** designed for the particular activity (eg, grab bars, cane, reachers, bus with lift, wedge pillow).
8. I require another person for **physical assistance** or, for an activity involving 2 people, I need unusual physical assistance.
9. I am **dependent** on another person to perform the activity.
10. **I no longer perform** the activity due to vertigo or a balance problem.

NA. **I do not usually perform this task** or **I prefer not to answer** this question.

*Cohen & Kimball, 2000

DIZZINESS HANDICAP INVENTORY

The Dizziness Handicap Inventory (DHI) can be used to determine the level of impairment felt by a patient with dizziness. It incorporates measurement of emotional functional and physical impacts of the dizziness on the person's life.

Answer how often the items correspond to your problem: YES, SOMETIMES, or NO

Questions:
(1) Does looking up increase your problem? (P)
(2) Because of your problem do you feel frustrated? (E)
(3) Because of your problem do you restrict your travel for business or recreation? (F)
(4) Does walking down the aisle of a supermarket increase your problems? (P)
(5) Because of your problem do you have difficulty getting into or out of bed? (F)
(6) Does your problem significantly restrict your participation in social activities such as going out to dinner going to the movies dancing or going to parties? (F)
(7) Because of your problem do you have difficulty reading? (F)
(8) Does performing more ambitious activities such as sports dancing household chores (sweeping or putting dishes away) increase your problems? (P)
(9) Because of your problem are you afraid to leave your home without having someone accompany you? (E)
(10) Because of your problem have you been embarrassed in front of others? (E)
(11) Do quick movements of your head increase your problem? (P)
(12) Because of your problem do you avoid heights? (F)
(13) Does turning over in bed increase your problem? (P)
(14) Because of your problem is it difficult for you to do strenuous housework or yard work? (F)
(15) Because of your problem are you afraid people may think you are intoxicated? (E)
(16) Because of your problem is it difficult for you to go for a walk by yourself? (F)
(17) Does walking down a sidewalk increase your problem? (P)
(18) Because of your problem is it difficult for you to concentrate? (E)
(19) Because of your problem is it difficult for you to walk around your home in the dark? (F)
(20) Because of your problem are you afraid to stay home alone? (E)
(21) Because of your problem do you feel handicapped? (E)
(22) Has the problem placed stress on your relationships with members of your family or friends? (E)
(23) Because of your problem are you depressed? (E)
(24) Does your problem interfere with your job or household responsibilities? (F)
(25) Does bending over increase your problem? (P)

Emotional items (9): 2 9 10 15 18 20 21 22 23 = SUM for all 9 items
Functional items (9): 3 5 6 7 12 14 16 19 24 = SUM for all 9 items
Physical items (7): 1 4 8 11 13 17 25 = SUM for all 7 items
Total = SUM for all 25 items

Response	**Points**
no	0
sometimes	2
yes	4

Interpretation:
- Minimum subscore or total score: 0
- Maximum emotional or functional subscore: 36
- Maximum physical subscore: 28
- Maximum total score: 100
- The higher the score the greater the handicap.

*Jacobson & Newman, 1990

CS-PFP TEST DIALOG

This is a test to quantify your ability to perform tasks which are important for living independently. The way we quantify these tasks is by measuring the time it takes for you to do the task, the weight you carry, and sometimes both. These tests are ordered from easiest to most difficult. It is important for you to pace yourself so you can complete all the tasks. I will show you where you are on this chart to help you monitor your total progress. You may stop the test at any time. Because this is a timed test conversation needs to be held to a minimum. I will accompany you throughout the testing process and give you specific directions for each task. Please tell me if you do not understand the directions or if you would like them to be repeated.

BELT: You will be wearing this belt throughout the test.

SPECIAL NEEDS AND CAUTION

Do you have any problems that we have not talked about? Please let me know if you would like a drink of water or to use the bathroom during the course of the test. As this test requires physical exertion please stop the test if you feel tightness in your chest, pain radiating down your left arm, pain in your lower jaw or at the base of your left scapula. If you need to rest do not wait for me to offer, please request a rest break.

RPE and SCORING TESTER: HOLD UP SCALE FOR SUBJECT

At the end of the test I will ask your perceived effort with this scale. During the test I want you to pay close attention to how hard you feel you are working.
Your Physical Functional Performance score is based upon the amount of weight you carry and how fast you complete each task. Perform each task safely, working AS FAST AS YOU CAN.
Do you have any questions before we begin?
Would you like to use the rest room before we begin?

Take the following assessments before starting:
Weight
Height
Age
Living Status

LOW EFFORT TESTS

WEIGHT CARRY

In this task you will carry a pan of weights from this counter to the counter behind you. Add sandbags to this pan until you have reached the maximal amount of weight you feel you can carry safely to the counter. (TESTER: stop and wait. Weigh pan before the test and if greater than 65 lbs, remove weight til it = 65 lbs) Put your hands by your side. At the word 'go' pick up the pan and carry it to the counter behind you. Set it down and put your hands by your side. Do you have any questions? Ready. Set. Go. STOP: PAN HITS FULLY ON COUNTER. Record time, weight, and units.

POURING

(TESTER: jug + cup + water = 9 lbs)

In this task you will carry a jug of water from this counter to the counter behind you where the "X" is located and pour from the jug into a cup.
If the subject carries less than 9 pounds in the previous task Read both A. and B.
If the subject carries more than 9 pounds skip to B.:

A. The jug is now full of water. Test the weight. You may adjust the weight by pouring some water out. (TESTER: stop instructions and wait).
B. Stand next to the counter. Put your hands by your side. At the word 'go' pick up the jug, carry it to the counter behind you and pour up to, but not over, the fill line of the cup. Set the jug down. Put your hands by your side. Do you have any questions? Ready. Set. Go. STOP: JUG HITS THE COUNTER. Record time, weight, and units.

JACKET

(TESTER: Select a jacket that is close to subject's size.) Position yourself at the foot of the bed. At the word 'go' pick up the jacket, put it on, pull the front together and then remove the jacket without zipping or buttoning it. Replace it on the bed. Do you have any questions? Ready. Set. Go. (TESTER: when the jacket is on say "remove"). STOP: WHEN SUBJECT'S SECOND HAND EMERGES FROM SECOND SLEEVE. Record time and jacket size.

SCARVES

In this task you will be asked to pick up four scarves from the floor. (TESTER: Place four scarves in a square pattern approximately one inch apart directly in front of subject). Facing the scarves, begin with your hands at your side. At the word 'go' pick up each scarf separately until you have gotten all four scarves, and then return to standing with your hands by your side at the place where you picked up the last scarf. Do you have any questions? Ready. Set. Go. STOP: SUBJECT IN A STANDING POSITION WITH ARM IN ALIGNMENT WITH TORSO. Record time.

REACH

This is not a timed test. In this test you will reach as high as possible. Push the shelf up as high as possible with your feet flat on the floor. Place the sponge on the shelf and let go then reach up and remove the sponge. You may lean on the wall or go up on your toes. (TESTER: Hand the subject the sponge. Ask "Can you go higher?"). TESTER: If too high, move shelf down 1 cm, retry. Record distance + correction distance for equipment.

MEDIUM EFFORT TESTS

FLOOR SWEEP

TESTER: Spread _ cup kitty litter in a 4 x 3 block square rectangle.
Here is a broom and dustpan. At the word 'go' sweep the kitty litter from the floor into the dust pan, set the pan on this counter. (TESTER: indicate position). Place the broom against the wall. Do this job to your own satisfaction as quickly as possible. Do you have any questions? Ready. Set. Go. STOP: DUST PAN HITS THE COUNTER Record time.

LAUNDRY 1

TESTER: CHECK TO BE SURE 9 LBS (2#; 2#; 2#; 3#) OF SAND WEIGHTS ARE PRESENT. Have frailer subjects practice opening the dryer door.) Start in front of the washer. At the word 'go,' open the washer door; transfer the clothes and the sandbags from the washer to the dryer. Close the dryer door. Do you have any questions? Ready. Set. Go. STOP: WHEN DRYER DOOR IS CLOSED. Record time.

LAUNDRY 2

Stand up to the dryer. At the word 'go' open the dryer door, transfer only the clothes from the dryer to the laundry basket. Leave the sandbags in the dryer. You may move the basket closer to the dryer if you wish. Place the basket of clothes on this counter. (TESTER: Indicate position and cue basket goes on this counter). Close the dryer door. Do this as quickly as possible. Do you have any questions? Ready. Set. Go. (TESTER: Place basket on the floor just behind subject and towards the same side as the dryer door handle.) STOP: BASKET FULLY HITS COUNTER OR WHEN DRYER DOOR IS CLOSED, WHICHEVER COMES **LAST**. Record time.

BED MAKING

(TESTER: Make sure that the pillows are placed on the chair with the comforter on top. The chair is facing the bed at a distance of 1 meter. The sheet should be folded and placed on the bed. Subject starts at the side of bed.) In this task you will make a bed. At the word 'go', put the fitted sheet on the bed and cover it with the comforter. Place the pillows on top of the comforter at the head of the bed. Working quickly, make the bed to your own satisfaction. Do you have any questions? Ready. Set. Go. STOP: WHEN SECOND PILLOW IS POSITIONED. Record time.

VACUUM

TESTER: (Measure 1/3 cup oats, spread on area avoiding edges. Vacuum is set on second from lowest position. Start with vacuum at edge of marked area.) This is the switch to turn the vacuum on and off and the handle release has been removed. (The subject turns the vacuum on and off.) At the word 'go' turn on the vacuum and vacuum-up all the oats from the rug. Return the vacuum to the starting place. Turn off the vacuum. Working quickly, do this job to your own satisfaction. Do you have any questions? Ready. Set. Go. STOP: RETURN TO START POINT. Record time.

FLOOR DOWN/UP

(TESTER: Use one chair for test. Have at least one hand on the belt to guard subject from dropping last few inches of the sit-down and if needed, to assist subject up from sit.)

Start in a standing position. At the word 'go' sit down on the floor, stretch your legs out in front of you, immediately stand up and put your hands by your side. You may use the chair seat for support. **Ask the subject:** *Do you feel comfortable about how you would sit on the floor and return to stand?* **If yes**---*proceed with test;* **If no**---*demonstrate one way to do the task.* **Ask the subject:** *Do you feel you are able to proceed with this task?* **If yes**---*proceed with task;* Do you have any questions? Ready. Set. Go. **If no**---*record '0' for score, record a comment, and proceed to next task.*

STOP: FULL STANDING POSITION WITH ARMS IN ALIGNMENT WITH TORSO. Record time.

FIRE DOOR

In this task you will open a fire door. Start behind this line (indicate line at the center of the doors) and go inside as if you had somewhere to go. You may use either hand. **Do not hold the door for me.** Do you have any questions? Ready. Set. Go. STOP: WHEN DOOR IS FREE FROM HAND OR BODY. Record time.

HARD EFFORT TESTS

BUS

In this task you will carry a weighted bag from the bench to the bus platform, up and down the steps, returning to the bench. You may carry the bag any way you like. (TESTER: Demonstrate the sequence while explaining.) Put as much weight into the bag as you can safely carry this distance. Test the weight.

This portion of the task is not timed. (TESTER: Bag is on the bench when it is being filled. Weigh the bag before the test and if the weight is greater than 65 lbs, remove weight till it = 65 lbs.) Sit on the bench with the bag on the bench next to you. At the word 'go' get up from the bench, pick up the bag, walk to the bus platform, climb the steps, turn around and descend the steps. Walk back to the bench, set the bag on the bench and sit down. Do you have any questions? Ready. Set. Go. STOP: SUBJECT SEATED ON BENCH. Record time and weight.

GROCERY

(TESTER: Point as you explain) In this task you will carry groceries from the store, up the steps to the bus platform, down the steps, out the door, around the cone in the hall, return, open the closed door, and place the bag(s) on the counter. Knowing this distance, place the maximal amount of weight you can safely carry into one or more of these grocery bags. You may carry the bags any way you like. You will not be timed on this portion of the task. (TESTER: Pause. Weigh the bag(s) before the test and if the weight is greater than 65 lbs, remove weight till it = 65 lbs.) Stand where the tile meets the "brick". At the word 'go' carry the bag(s) to the bus stop, climb the steps, descend the steps, walk out the door into the hall and around the cone, return and open the door and set them on the counter. Do you have any questions? (TESTER: Have subject start with the bag handles in hand, but not lifted off the ground) Ready. Set. Go. STOP: ALL BAGS PLACED ON COUNTER. Record time, weight, and units.

Offer the subject a drink of water.

STAIR CLIMB

You will climb one flight of stairs. At the word 'go', start up the steps until you reach the next landing, and then stop. You may use the handrail, but do not pull yourself up the steps. Do you have any questions? Ready. Set. Go. STOP: WHEN FIRST FOOT CONTACTS STEP #11. Record time and *number of steps.

ENDURANCE WALK

At the word 'go,' walk at a pace that will allow you to cover the GREATEST distance you can in 6 minutes. You may cover several laps of this hallway turning around at the cone at the end of the hall. Walk as quickly as possible minimizing the time it takes to turn around at the ends of each lap. This is a busy hallway, walk around obstacles and keep up your pace the best you can. I will give you your time each minute. You may rest any time you need to. Set your own pace. I will follow you. Do you have any questions? Ready. Set. Go. (TESTER: Walk just off and behind outside shoulder of subject.) STOP: ANNOUNCE "15 sec, ... 10, ... 5, 4, 3, 2, 1, STOP. Record distance via number of full laps and partial lap amount.

TOTAL RPE

(TESTER: Hold RPE scale up for subject to see.) Using this scale, I want you to evaluate your feeling of exertion throughout the entire test. Do not focus on one particular task or one factor, such as fatigue, intensity, or leg pain. What one number would you choose? Record RPE numerical value.

*Cress et al, 1996

APPENDIX D: VESTIBULAR REHABILITATION EXERCISES

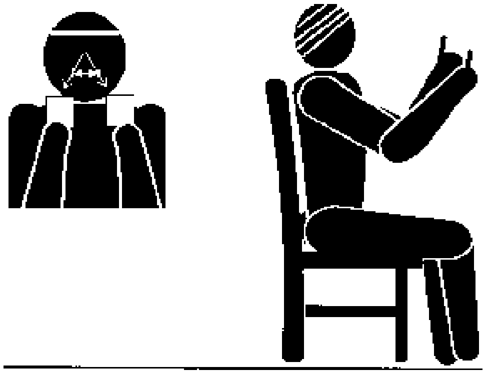
SACCADES

Purpose of Activity: This activity will help you to tolerate quick eye movements such as those needed for reading.

1. Sit in a comfortable position, hold a playing card (king or queen) in each hand at about eye level and about 18 inches apart at a comfortable distance.

2. Keep your head still, move your eyes quickly from one card to the other without stopping in between cards. Do not go so quickly so as to blur the targets. **Remember to only move your eyes and <u>not</u> move your head.**

3. At first, use a larger target. As you improve, try to focus on progressively smaller details of the face card such as the nose, eye, or mouth of each card. Also as you improve, try to move your eyes more quickly.



4. Repetitions: Repeat **15 to 20** times in the horizontal direction.

Repeat **15 to 20** times in the vertical direction.

Repeat **15 to 20** times in both diagonal directions: right/up to left/down; right/down to left/up.

Do **2-3** times daily.

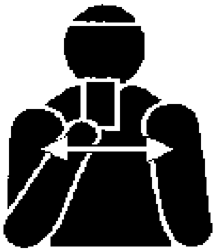
VISUAL TRACKING

Purpose of Activity: This activity will help you to smoothly follow a moving target. This type of eye movement would be needed for watching a car cross in front of you at an intersection or following a tennis ball during play.

1. Sit in a comfortable position and hold a playing card (king or queen) about 12 inches in front of your eyes.

2. Slowly move the card horizontally to the right, to the left, and back to the center. **Keep your head still** and follow the index card with just your eyes. You should then repeat this card movement in the vertical (up, down, and back to center) direction and finally in both diagonal directions (right/up to left/down; right/down to left/up).

3. To progress, move your arm at faster and faster speeds. Remember to keep your head still during this exercise and to follow the care with only your eyes.



4. Repetitions: Repeat 15 to 20 times in the horizontal direction.

Repeat **15 to 20** times in the vertical direction.

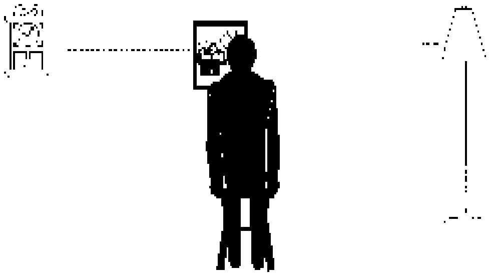
Repeat **15 to 20** times in both diagonal directions: right/up to left/down; right/down to left/up.

Do **2 to 3** times daily.

TARGETS

Purpose of Activity: This activity will help you keep your vision stable with large head movements. This type of movement is often needed when changing lanes while driving.

1. While seated in a comfortable chair, find three objects in the room that are at eye level. One of the objects should be to your far left, one should be in front of you, and one should be on your far right.



2. Move your head to the left target, then the center target, then the right target, then center, then left. This completes one cycle.

3. Repetitions: Repeat **10 to 15** cycles without stopping at each target.

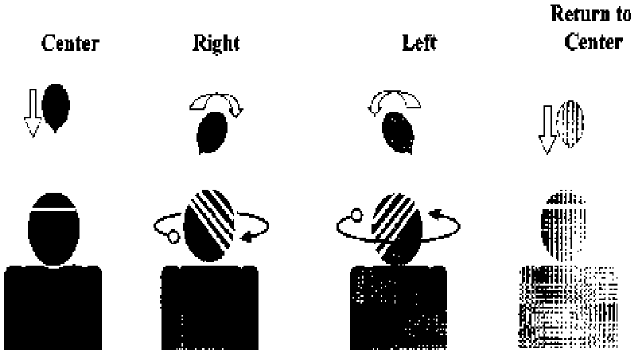
Repeat **10 to 15** cycles, but stop for one second at each target.

Do **2 to 3** times daily.

HORIZONTAL HEAD MOVEMENTS

Purpose of Activity: This activity will help you keep your vision stable with head movements. This is similar to watching for a break in traffic.

1. Sit in a comfortable chair with your feet flat on the floor and your hands on your thighs.



2. Keeping your trunk still, quickly turn your head and look to the right, then turn your head and look to the left without stopping in the center, and then look to the center and focus on an object for five seconds. This completes one cycle.

3. For best results, briefly focus your eyes on an object or target to both **right and left directions.**

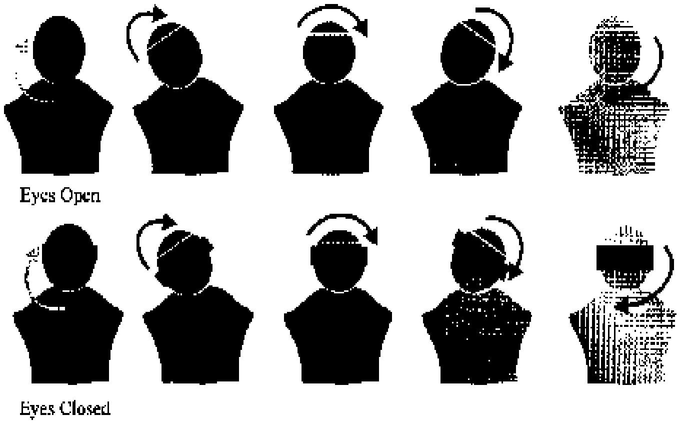
4. Repetitions: Repeat **15 to 20** times.

Do **2 to 3** times daily.

HEAD CIRCLES

Purpose of Activity: This activity will help you keep your vision stable with smaller head movements. This would be similar to standing in an aisle of a store and looking for an item on the shelves.

1. Sit in a comfortable chair and move your head in a circular motion with your eyes open. Let your eyes lead the way. Each full circle completes one cycle.



2. Repeat step one with your eyes closed.

3. Repetitions: Repeat **15 to 20** times in the clockwise direction.

4. Repeat **15 to 20** times in the counter clockwise direction.

Do in both directions **2 to 3** times daily.

FOCUSING WITH HEAD TURNS

Purpose of Activity: This activity will help you stabilize your gaze with quick, short head movements. This type of movement is used while driving.

1. Sit in a comfortable chair and bring your index finger or a playing card approximately 10 inches in front of your nose.

2. Focus on your finger or the card while turning your head from side to side. Try not to let the object blur.

3. Gradually increase the speed of the head turns.

4. Repetitions: Repeat **15 to 20** times.

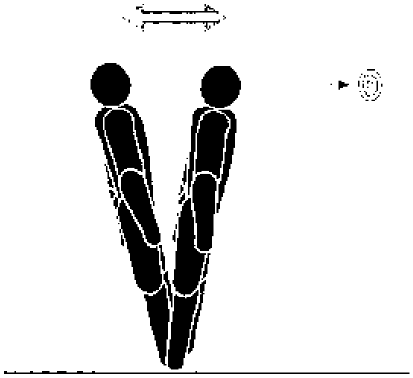
Do **2 to 3** times daily.

ANKLE SWAYS

Purpose of Activity: This activity will help you build good strategies for keeping your balance while standing.

1. Stand with your feet apart by a shoulder width, with equal weight on both feet and your arms relaxed at your side. Look straight ahead and close your eyes.

2. Slowly shift your weight forwards and backwards. Do not move very far. **Do not bend at your hips.** All movement should be at your ankles.



3. Shift your weight from side to side, placing more weight first to your right side and then to your left side. **Do not bend at the hips.**

4. Do this exercise with your back near a wall or with someone **spotting** you from behind.

5. Repetitions: Repeat **15 to 20** times.

Do front back and side-to-side directions **2 to 3** times daily.

CIRCLE SWAYS

Purpose of Activity: This activity will help you build good strategies for keeping your balance while standing.

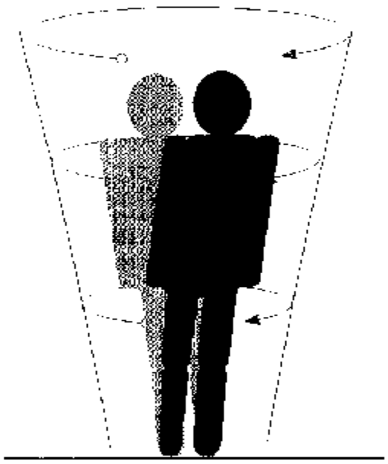
1. Stand with your feet apart by a shoulder width, with equal weight on both feet and your arms relaxed at your side.

2. Breath deeply and relax. Focus your thoughts on feeling your feet in contact with the floor.

3. Look straight ahead and find an object to focus on. Practice swaying your body in a circle. Sway forward, to the right side, to the left side, and forward again. Each full circle completes one cycle.

4. Begin with small circles. **Do not bend at the hips.**

5. Gradually increase how far you can move your body without bending your hips and without taking a step.



6. Do this exercise with your back to the wall with someone **spotting** you from behind.

7. As your ability to do this activity improves, try it with your eyes closed.

8. Repetitions: Repeat **15 to 20** times.

Reverse the direction of the sway.

Repeat **15 to 20** times.

Do both directions **2 to 3** times daily.

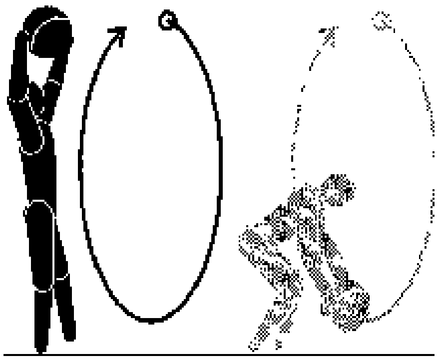
BALL CIRCLES

Purpose of Activity: This activity will help you build good strategies for keeping your balance while standing.

1. Stand with your feet apart by a shoulder width, with equal weight on both feet. Hold a large ball or pillow with both hands and your arms straight. Keep your eyes on the ball or pillow.

2. Keeping your arms straight, move the ball in a large complete circle in a clockwise direction. Follow the ball with your head and eyes.

3. Make the circle large by lifting the ball or pillow high over your head and low to the ground, bending your knees to touch the ground with the ball or pillow. Try to move smoothly and continuously.



4. If dizziness begins or increases, stop the movement until the feeling subsides and then begin again.

5. Repetitions: Repeat **15 to 20** times.

Reverse the direction of the circle.

Repeat **15 to 20** times.

Do both directions **2 to 3** times daily.

GAIT WITH HEAD MOVEMENT

Purpose of Activity: This activity will help you build stable head movements while walking. This type of movement occurs when walking down the aisle of a grocery store searching for an item.

1. Begin walking at your normal speed. Walk near a wall so that you can reach out to steady yourself if necessary. A hallway is an excellent place for this activity in the beginning.

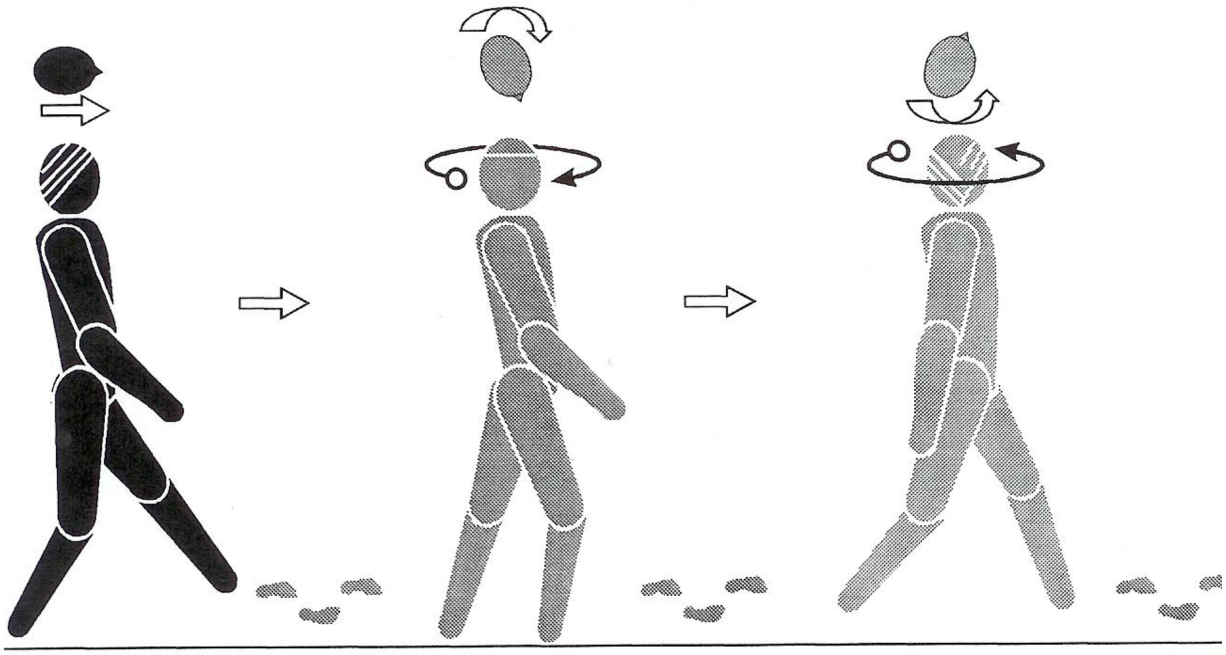
2. After three steps, turn your head and look to the right while continuing to walk straight ahead.

3. After three more steps, turn your head and look to the left while continuing to walk straight ahead.

4. To increase the difficulty of this task, go from a solid floor to a carpeted floor, or walk outdoors on an uneven surface. Thick lawns usually are the most difficult surface.

5. Repetitions: Repeat **15 to 20** times.

Do **2 to 3** times daily.



*All 10 exercises and directions were adapted from Gans (2001).

APPENDIX E: MATHEMATICAL CALCULATION OF CALORIC RESPONSES

Caloric Weakness: Input SPV from each of four irrigations

$$\frac{(RW + RC) - (LW + LC)}{(RW + RC + LW + LC)} \quad X \quad 100 \quad = \quad \%\ \text{Caloric Weakness}$$

Unilateral: $\geq$ 25% = Caloric weakness or unilateral vestibular disorders in the ear with the smaller total SPV.

Bilateral: $\frac{(RW + LW)}{2} \quad X \quad 100,$ If < 11% on warm irrigations <u>OR</u>

$\frac{(RC + LC)}{2} \quad X \quad 100,$ If < 6% on cool irrigations

Directional Preponderance: Input SPV from each of four irrigations

$$\frac{(RW + LC) - (LW + RC)}{(RW + LC + LW + RC)} \quad X \quad 100 \quad = \quad \%\ \text{Directional Preponderance}$$

Abnormal: $\geq$ 30% = SPVs of nystagmus are stronger in a particular direction

Typically a sign of a "central" pathology BUT can be indicative of a chronic peripheral pathology with the nystagmus beating in the direction of the "strong" ear (or SPV to the affected ear).

Fixation Suppression: Comparison of average SPV before and after fixation

Normal = SPV with eyes closed is greater than eyes open by approximately 50%.

Peripheral = Although a caloric weakness and other abnormal test results may exist, SPV with eyes closed is greater than eyes open by approximately 50%.

Central = Regardless of the presence of a caloric weakness or directional preponderance, SPV with eyes open is greater than or equal to SPV with eyes closed.

KEY:

RW = Right Warm
RC = Right Cool
LW = Left Warm
LC = Left Cool

* Jacobson, Newman, & Peterson, 1997

VITA

Micah Leslie Bradshaw Klumpp was born in Oklahoma in 1977. After receiving her Bachelor and Master of Arts of degrees from LSU, she practiced audiology in rural Alabama serving an aging population with balance and hearing impairments. Micah immediately observed the need for audiologists to collaborate with many other healthcare fields in clinical practice and in research to better serve their patients. With her fellowship and enhancement awards, Micah was able to pursue interdisciplinary research involving the effects of vestibular rehabilitation on kinematic performance and physical function, aging and the vestibulo-cardiac reflex, aging and vestibular myogenic potentials, and discovery vs. guided learning of hearing aid insertion.

A recipient of the LSU Life Course and Aging Center’s Graduate Fellowship and Enhancement Awards and the LSU Graduate School’s Doctoral Fellowship Award, Micah currently practices audiology at Ochsner Health Center in Baton Rouge, LA, where she performs comprehensive audiologic and vestibular assessments and treatments to patients across the life span. She, her husband, and their two children reside in the Baton Rouge area.