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Reliability of the Dynamic Gait Index in Vestibular Disorders

Diane M. Wrisley
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RELIABILITY OF THE DYNAMIC GAIT INDEX IN VESTIBULAR DISORDERS

by

DIANE M. WRISLEY

B.S., June 1984, State University of New York at Buffalo

**A Thesis Submitted to the Faculty of the Graduate Program in Physical Therapy in Partial
Fulfillment of the Requirements for the Degree of**

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PHYSICAL THERAPY

**OLD DOMINION UNIVERSITY
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ABSTRACT

RELIABILITY OF THE DYNAMIC GAIT INDEX IN VESTIBULAR DISORDERS

Diane M. Wrisley
Old Dominion University, 1998
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The purpose of this study was to examine the inter-rater and intra-rater reliability of the Dynamic Gait Index (DGI) when used with patients with vestibular disorders. Subjects included 30 patients aged 27-88 years, with vestibular disorders, who were referred for vestibular rehabilitation. Subjects' performance on the DGI was concurrently rated by two physical therapists experienced in vestibular rehabilitation to determine inter-rater reliability. To determine intra-rater reliability each subject repeated the DGI one-hour later. Percent agreement and kappa statistics were calculated for individual DGI items. Kappa statistics for individual items were averaged to yield a composite kappa score of the DGI. Total DGI scores were evaluated for inter-rater and intra-rater reliability using Spearman rank order correlation coefficient. Inter-rater reliability of individual DGI items varied from poor to excellent based on kappa values. Composite kappa values demonstrated good overall inter-rater reliability of total DGI scores. Spearman Rho demonstrated excellent correlation between total DGI scores of both raters. Intra-rater reliability of individual items varied from fair to excellent based on kappa values. Composite kappa values demonstrated good overall intra-rater reliability of DGI. Fair but significant correlation was demonstrated between total DGI scores using Spearman Rho. It was concluded that the Dynamic Gait Index demonstrated only fair inter- and intra-rater reliability when used with subjects with vestibular disorders.

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Dysfunction of the vestibular system can result in dysequilibrium manifested by ataxic gait and postural instability exacerbated by head and body turns or alteration of sensory inputs. To date there have been no means to quantify the gait ataxia seen with vestibular disorders. Clinicians would benefit from a reliable functional gait assessment to determine those who might benefit the most from vestibular rehabilitation and to document clinical progress. The purpose of this study was to find an assessment to meet these needs.

The anatomy and physiology of the vestibular system will be discussed in terms of the balance system and outputs to the vestibular ocular and vestibular spinal reflexes. Signs and symptoms of vestibular dysfunction and methods of evaluating vestibular dysfunction are discussed. A review of current literature regarding postural stability tests and functional gait scales follows. Studies documenting use of these tools in patients with vestibular dysfunction are investigated. Various aspects of reliability are discussed and the Dynamic Gait Index (DGI) is introduced as a possible functional gait scale for use with patients with vestibular disorders.

Vestibular System Anatomy and Physiology

The human balance system is comprised of three components: the peripheral sensory apparatus, the central processing system and the motor outputs (figure1).^{1,2} The peripheral sensory system includes the sensory receptors in the visual, vestibular, proprioceptive and auditory systems.² These peripheral sensory receptors send information regarding head position and movement to the central nervous system.^{1,2} The

central nervous system, specifically the vestibular nucleus and cerebellum interprets these signals, and compares and combines them with other sensory input to determine head and body orientation.³ From this information, the central nervous system directs the motor output to the eyes and the motor output to the muscles through the vestibular ocular reflex and vestibular spinal reflex respectively.^{2,3} The vestibular ocular reflex drives eye movements that stabilize vision during head and body movements.^{3,4} The vestibular spinal reflex stimulates primarily the extensor muscles of the head, neck and extremities to maintain head and body stability.^{4,5} The central nervous system monitors the motor response of the vestibular ocular reflex and vestibular spinal reflex through feedback from sensory receptors and adjusts the output as needed.^{2,3}

The peripheral sensory apparatus of the human vestibular system is enclosed in the bony labyrinth which consists of several cavities on the petrous portion of the temporal bone that house both vestibular and auditory organs (figure 2).^{1,2,3} The membranous labyrinth is suspended in the bony labyrinth by perilymphatic fluid and connective tissue. The membranous labyrinth expands into sensory epithelium in specialized regions. These areas serve as transducers for auditory and balance stimulation². The vestibular portion of the membranous labyrinth consists of two distinct sets of structures: three directionally sensitive semicircular ducts and the otoliths, a pair of sac like structures called the utricle and saccule^{1,2}. Organization of membranous labyrinth is depicted in figure 3.

Both ends of each semicircular canal terminate in the utricle however prior to terminating one end dilates to form the ampulla. Within this ampulla the epithelium thickens to form the ampullae crest. Within the ampullae crest are vestibular hair cells,

which comprise the sensory organ in the inner ear.^{3,4} These hair cells are covered with a gelatinous cap called the cupula (figure 4). Surrounding the cupula is endolymph, an unusual extracellular fluid due to the similarity of the ion composition to intracellular fluid.^{3,4} This fluid is viscous and exerts inertia on the cupula so that when the head is turned the fluid places pressure on the cupula and deflects it (figure 4).^{1,4} Movement in one direction of the cupula is excitatory and in the opposite direction is inhibitory.

The semicircular canals are positioned at right angles to each other and positioned as two walls and a floor tipped back about 30 degrees from horizontal^{1,2,6}. They are named the anterior or superior, posterior and horizontal. The canals are functionally paired with the canal on the opposite side that resides in the parallel plane. For example, the right anterior canal is paired with the left posterior canal (figure 5). This allows for a push-pull mechanism so that when one semicircular canal in the pair is excited the other is inhibited^{1,2,6}. This pairing provides three advantages. First, it allows sensory redundancy, so that if one side is impaired the central nervous system will still receive information from the vestibular system. Second, this pairing allows the brain to ignore changes in neural firing patterns due to changes in body temperature or chemistry. Thirdly, this pairing assists in compensation for sensory overload such as when the head is turned rapidly.^{1,2}

The semicircular canals respond to angular motion of the head that is either horizontal or vertical. Receptors in the semicircular canals are very sensitive; they respond to angular accelerations of .1degree/sec^{2,7}. They will not respond to steady state motion of the head. During prolonged motion of the head, the cupula returns to its resting state.

As in the ampullae of the semicircular canals, a portion of the utricle and saccule are also thickened and contain hair cells. This zone is called the macula. The macula is covered with a gelatinous substance in which are embedded crystals of calcium carbonate, called otoconia (figure 6)^{3,6}. These otoconia cause the otoliths to be sensitive to gravity. The macula of the utricle lies roughly in the horizontal plane when the head is held erect. When the head is tilted or undergoes linear acceleration, the otoliths deform the gelatinous mass, and deflect the hairs of the receptor cells. The macula of the saccule lies vertically when the head is held erect. It responds selectively to vertically directed linear force³. The otoliths differ from the semicircular canals in two ways. They respond to gravitational force and tilt or linear motion instead of angular motion.⁷

Neurons from both the semicircular canals and the otoliths travel through the vestibular portion of the eighth cranial nerve. They have their cell bodies in the vestibular ganglion (Scarpa's ganglion). The neurons enter the brain in the pons where most terminate in the vestibular nuclei complex in the floor of the fourth ventricle of the medulla however a certain portion of the neurons connect with the cerebellum, the reticular formation, the thalamus and the cerebral cortex.^{3,7} Information from the semicircular canals and otoliths regarding head position is transmitted from the vestibular nuclei to the medial longitudinal fasciculus. The medial longitudinal fasciculus transmits the information regarding head movements to the nuclei of cranial nerves 3,4, and 6, the nuclei that innervate the muscles of the eye^{1,2,3,4}. This information is used to produce eye movements in the opposite direction of head movements so that stable vision is maintained. This process is known as the vestibular ocular reflex. Figure 7 illustrates the vestibular ocular reflex function with head turning to the right¹⁻⁴. As the head is turned to

the right the cupula in the ampullae of the right horizontal semicircular canal is deflected and causes excitation of the hair cells. This information is transmitted to the vestibular complex. The vestibular nucleus sends signals to the left abducent nucleus and right oculomotor nucleus via the medial longitudinal fasciculus to produce eye movement to the left with the same magnitude as the head movement to maintain stability of the visual image on the retina^{4,6}.

The lateral vestibular nucleus receives input not only from the semicircular ducts and the macula of the utricle but also from the spinal cord and the cerebellum. Many of the cells in the dorsal part of the nucleus send axons into the lateral vestibular spinal tract that terminates in the ipsilateral ventral horn of the spinal cord³. The lateral vestibular spinal tract is facilitative to the both alpha and gamma motor neurons that innervate extensor muscles of the limbs⁴. This tonic excitation of the extensors allows us to maintain an upright body posture⁴. The medial vestibular nucleus gives rise to the medial vestibular spinal tract. The medial vestibular spinal tract terminates bilaterally in the cervical region of the spinal cord to make connections with motor neurons innervating the neck muscles³. This allows for reflex control of neck movements so that the position of the head can be maintained accurately and is correlated with eye movements^{3,4}. The reticulospinal tract receives input from all vestibular nuclei as well as the other sensory and motor systems that contribute to balance³. This tract projects ipsilaterally and contralaterally through the entire spinal cord. The tract is poorly defined but is probably involved in most balance activities including postural adjustments to extr vestibular sensory input (auditory, visual and tactile stimuli)¹.

Normal Function of Postural Control System

Human balance has been defined as the ability to maintain the center of gravity over the base of support within a given sensory environment.⁸ The ability to do this involves the ability to organize sensory information within the central nervous system and to execute appropriate musculoskeletal responses.⁹ The tasks required for this can be separated into biomechanical components, organization of sensory information and coordination of motor responses.^{8,9}

The biomechanical components of balance involve the ability to maintain the center of gravity over the base of support. Nashner defines limits of stability as the maximum amount a person can shift their center of gravity from vertical without loss of balance. This can be pictured as an inverted cone (figure 8).⁸ In normal adults anteroposterior limits of stability are approximately 8 degrees anterior and 4 degrees posterior. A person's height and stance width define their lateral limits of stability.⁸

In general a person's center of gravity approximates the center of the limits of stability. Limits of stability and center of gravity alignment may be altered with musculoskeletal dysfunction. Weakness or impaired sensation in one lower extremity may change a person's center of gravity alignment over the non-affected leg and shift the limits of stability toward the non-affected side. This shift is necessary to provide a stable postural environment.⁸

When a person moves their center of gravity outside of their base of support a step or stumble is required to prevent a fall. Nashner has described a series of balance strategies used to maintain the center of gravity within the base of support.⁸⁻¹⁵ Each balance strategy has certain conditions under which it is more effective. The

determination as to which balance strategy is most effective in a given situation is made based on current task requirements, current sensory information available and past experiences.¹⁰

On firm level surfaces, with slow perturbations and the center of gravity aligned near the center of the limits of stability, the ankle strategy is most effective. The ankle strategy uses a sequence of muscle activation distal to proximal, with muscle activation on the opposite side as the direction of sway (figure 9).^{8, 10} For example, if a person is standing on a moveable platform and the platform is moved backward the person sways forward. The muscles activated are the gastrocnemius, hamstrings and the paraspinals, in that order, bringing the center of gravity posteriorly over the base of support. This activation pattern exerts compensatory torque about the ankle. When the support surface is narrow or the center of gravity is near the outer limits of the stability cone, the ankle torque exerted by the ankle strategy is ineffective.^{8, 9}

The hip strategy is the most effective near the outer limits of stability, or when standing on a narrow or soft surface. This strategy is also more effective if the perturbation is faster or greater in magnitude.⁹ The sequence of muscle activation for the hip strategy is proximal to distal and occurs on the same side of the body as the direction of sway (figure 9).^{8, 10} When someone is standing perpendicular on a narrow platform, such as a two by four, and the platform is perturbed backwards, the person sways forward. The muscles activated are the abdominals and quadriceps causing the hips to flex and bring the center of gravity posteriorly over the base of support.⁸⁻¹⁰ This activation pattern produces a compensatory horizontal shear force against the support surface but little, if any, ankle torque.^{8, 10}

If the support surface is intermediate in length or the perturbation is intermediate in magnitude, the postural response patterns are complex and resemble a combination between hip and ankle strategies. These complex movements act with a combination of torque and horizontal shear forces and motions about the ankle and hip joint.⁸⁻¹⁰

When these postural responses are not sufficient to maintain the center of gravity within the base of support a stepping strategy is used. A step is taken in the direction of the sway to maintain upright posture.⁸⁻¹⁰

In order for the central nervous system to choose the most effective balance strategy the position of the head and body in space must be detected.¹⁰ The ability to perceive one's relationship to support surface, gravity and surrounding objects involves a complex organization of visual, vestibular and somatosensory (skin pressure receptors on the feet plus muscle and joint receptors which signal movement of particular body parts) information.⁸ No one sense directly measures the body's center of gravity. Vision measures the orientation of the body in relationship to surrounding objects, somatosensory input gives information of the body in relation to the support surface and vestibular input gives information in regard to head orientation relative to gravity. Under different situations a sense may be absent or inaccurate.⁸ For instance, when standing on a sidewalk and a bus suddenly moves, a person will believe they are moving if only vision is used for orientation and they will exhibit a resultant postural correction. If the other senses are not available to detect that the person is not moving and corrections are not made for the initial response a fall or stumble may occur.⁸ The central nervous system must choose which sense to rely on based on conditions of the task, present conditions and past experiences.¹⁰ Because there is a redundancy to orientation

information postural stability can be maintained with absence of one or two senses, although it makes resolving sensory conflict difficult. The absence of all three sensory inputs makes postural stability very challenging if not impossible.⁸

There appears to be a hierarchical arrangement to the use of sensory information. Under most conditions it appears that the central nervous system relies on visual and somatosensory inputs preferentially with the vestibular system used as an internal reference or comparator for the other two senses.⁸ The visual and somatosensory systems are more sensitive to subtle change than the vestibular system. Because both senses use external reference they are more prone to erroneous orientation such as walking on sand or with a moving visual field. Under these conditions the information from the internal reference of the vestibular system is vital.^{8, 16-19}

These motor responses used to regain upright stance following a perturbation were termed “automatic postural reactions” by Nashner.^{8,11-14} He referred to these reactions as automatic because they precede the earliest volitional movements and are not modifiable by conscious effort. However they appear to be more centrally organized and adaptable than segmental or spinal level reflexes.^{8, 12} Normal adults demonstrate similar magnitude, timing and direction of responses when exposed to similar perturbations.^{8,13,14} These automatic responses are not limited to the lower extremity. If a person is perturbed while seated similar automatic responses will be exhibited to maintain their upright posture. Similarly if a person is grasping a handle with the upper extremity during a linear translation while standing there is a rapid recruitment of upper extremity muscles while the lower extremity muscles are relatively quiet.^{8,15} Automatic balance reactions controlled at a subcortical level have several advantages. The central nervous system

needs to integrate several sensory inputs to determine body position. It needs to select balance strategies based on these current conditions as well as past experiences. This could not be accomplished if these reactions were regulated at a spinal reflex level. The speed of muscle action needed to correct postural instability is faster than most volitional movements. Without postural reactions being automatic, it would be difficult to correct sudden loss of balance fast enough to prevent a fall. The automatic function of the postural responses allows the central nervous system to coordinate sensory input, determine appropriate motor response and activate this response quickly enough to prevent a fall or loss of balance.^{8,10}

Vestibular System Dysfunction

Patient Signs and Symptoms

Dysfunction of the vestibular system results in disorders of the two primary outputs from the vestibular system, the vestibular ocular reflex and the vestibular spinal reflex.^{22,23} Disruption of the vestibular ocular reflex results in oscilopsia or the inability to stabilize vision during movement. This may be described by patients as a bouncing of the visual field. Patients may also complain of difficulty focusing during reading, watching television or driving.²² Disruption of the vestibular spinal reflex results in a sensation of being off balance or a staggering gait.²³

Symptoms of vestibular dysfunction may also be varied depending on whether the otoliths or semicircular canals are affected. Damage to the semicircular canals tends to result in vertigo (the perception that the world is spinning or the person is spinning) and nausea. Damage to the otoliths results in perception of tilting, vertical movement or an antero-posterior movement.²²

During nonpathologic function of the vestibular system the firing rates of the right and left vestibular nuclei are in balance with each other while the head is still.³

Following an acute lesion of the peripheral vestibular system, the firing rate in the affected nucleus decreases and the brain interprets this as an apparent increase in firing rate on the nonaffected side.²² This is interpreted as movement toward the nonaffected side, although there is no change in head position or head movement. The imbalance between the firing rates of the two vestibular nuclei causes the disturbances in the vestibular ocular and vestibular spinal reflexes described above.²²

Unilateral peripheral vestibular disorders from viral infection, trauma or vascular insult can result in symptoms of vertigo, nausea and dysequilibrium. Patients will present with an ataxic gait that usually increases with head turns, quick body turns and altered sensory input due to the impaired functioning of the vestibular system in monitoring head position in space and the lack of redundant sensory inputs.²²

Bilateral peripheral vestibular disorders from trauma, ototoxicity or congenital disorders will typically present with a primary complaint of dysequilibrium with gait ataxia.²² They demonstrate great difficulty maintaining upright posture with either decreased visual or somatosensory inputs, as they are unable to utilize vestibular inputs to maintain equilibrium.²⁴ Patients with bilateral vestibular disorders typically do not complain of vertigo, as there is no asymmetry in vestibular function. Vertigo and nausea result from the inconsistencies in information coming from vision, vestibular and proprioceptive inputs.²² One of the main complaints of patients with bilateral vestibular disorders is oscillopsia, as the vestibular ocular reflex is unable to maintain stable vision during movement.^{24,25}

Patients with cervical vertigo, benign paroxysmal positional vertigo or positioning vertigo may complain of vertigo or lightheadedness induced by position changes or head movements. They may also complain of dysequilibrium, gait ataxia and impaired postural stability in situations with altered sensory inputs or with head or body movements. Symptoms from these disorders are believed to be due to irritative dysfunction of the vestibular complex and a mismatch between sensory inputs to the brain.²⁶

Vestibular Function Testing

The function of the vestibular system is measured indirectly by currently available vestibular laboratory tests through motor output of the vestibular ocular and vestibulospinal reflexes.²⁷ Although the ability to measure vestibular function through use of the vestibular ocular reflex is widely accepted by the otolaryngology community,^{17,20,22,27,28} the use of posturography to measure vestibulospinal function is controversial.^{29,30} Postural stability as measured by computerized dynamic posturography (CDP) is influenced by several other systems in addition to the vestibulospinal system.^{30,31} Vestibular function testing consists of ocular motor testing, positional testing, caloric testing, rotational testing and CDP.^{27,28}

The function of the ocular motor system must be measured prior to vestibular function testing. Ocular motor dysfunction can mimic vestibular dysfunction during the testing if they are not ruled out first.²⁷ Ocular motor testing is designed to uncover motor control problems in the rapid and slow eye movement systems. The components of ocular motor testing are: nystagmus suppression with fixation, gaze evoked nystagmus with horizontal and vertical gaze, spontaneous nystagmus, measured in the dark and with

eyes closed, saccades, ocular pursuit, optokinetic nystagmus.²⁷ Ocular motor abnormalities indicate central nervous system dysfunction.²⁸

Positional testing is designed to evaluate for static positional nystagmus or vertigo and benign paroxysmal positional vertigo. "Static" positional testing is performed by placing the patient in the following positions and observing for nystagmus and vertigo: Supine head left, left lateral, supine head right, right lateral, and supine.²⁷ Benign paroxysmal positional vertigo (BPPV) is induced through the Dix-Hallpike maneuver, a rapid change from erect sitting to supine head-hanging left, right or center position.²⁸ BPPV is diagnosed with nystagmus that is predominantly torsional, has a latency of 5-10 seconds, lasts a short duration (15-45 seconds), is associated with vertigo and fatigues with repeated provocation.²⁷

The caloric test is used to determine the output of the vestibular system. Caloric testing is based on establishing a thermal gradient across the horizontal semicircular canals when either cold or warm air or water is inserted into the external auditory canal. A convection current is developed that is thought to induce changes in the firing rate of the vestibular nerve.²⁷ The nystagmus is measured using electronystagmography, electrodes on the face measuring changes in the corneal-retinal dipole potential of the eyes that occurs with eye movements.²⁸ The peak slow phase velocity of any caloric stimulation is the best determinant of the intensity of the vestibular response. The symmetry and intensity of caloric responses are examined.²⁷ Responses will be absent, bilaterally reduced, asymmetric or hyperactive.

Rotational vestibular testing relies on the natural stimulation of the labyrinth, angular acceleration. The patient sits on a computer controlled turntable and is rotated

right and left. The vestibular ocular reflex is assessed independently of vision by rotating the patient with the eyes open in the dark.²⁷ The rotation provides stimulation to both members of the co-planar pair of the semicircular canal simultaneously. One member is inhibited and the other excited. Nystagmus is measured using electronystagmography technology and the slow component of the nystagmus is transformed to yield the slow component velocity. This can be compared to the turntable velocity to establish the response parameters of gain, phase and symmetry.²⁷ Rotational chair testing reveals physiologic vestibular function at a wider spectrum of frequencies than caloric testing can reveal.

The sensory organization portion of computerized dynamic posturography (CDP) was designed to quantify postural sway under various sensory conditions to demonstrate the ability to utilize and organize sensory inputs for balance.³¹ The test is performed by having a subject stand on a force platform. For the first two conditions the subject stands in a normal stance with the eyes open and then closed. The third condition measures postural sway with conflicting visual inputs by sway referencing of the visual surround. Sway referencing is accomplished by having the visual surround move in the same direction and magnitude as the subjects sway. Condition four utilizes a sway referenced surface, or force platform, to measure postural stability with inaccurate somatosensory inputs. This quantifies the ability to balance with only visual and vestibular inputs. Conditions five and six measure the ability to utilize vestibular inputs to balance by having the subject first close their eyes with sway referenced support surface and then maintain upright stance with both visual surround and support system sway referenced. The amount of sway during each condition is compared to normative scores. Increased

sway or falls during conditions five or six are considered indicative of vestibular dysfunction.³¹

Rehabilitation

Recovery of vestibular disorders depends on the site and mechanism of the lesion. Most vestibular disorders will spontaneously resolve in six weeks to three months. Treatment for disorders that do not spontaneously resolve includes medication, surgery and physical therapy.^{22,23}

Physical therapy for vestibular disorders is based on several mechanisms. First, exercises may be directed at habituating positions that provoke symptoms.³² Second, exercises that stimulate the vestibular ocular reflex are used to encourage central compensation for the vestibular dysfunction and allow the brain to more effectively use remaining vestibular information to stabilize vision.^{22,32} Third, postural stability exercises involving a narrow base of support, head turns and quick body turns especially in altered sensory environments are used to facilitate normal function of the vestibular spinal reflex.^{22,32} Fourth, exercises may be implemented that encourage alternative strategies for vestibular function.²²

Many studies have explored the improvement that patients with various types of vestibular dysfunction experience with vestibular rehabilitation. Outcome measures have included self-report measures^{33,34} such as the Dizziness Handicap Inventory,³⁵ disability scores,³⁶⁻³⁹ posturography^{39,40} as well as general gait and balance measures.^{40,41} Despite the variety of outcome measures, most authors have reported improvements in approximately 80% of patients.^{33,34,36-41}

Postural Stability Testing

The quest to quantify gait ataxia and postural instability began in the 19th century.⁴² Although initially these tools were developed to assess balance problems secondary to tabes dorsalis, alcoholism, and venereal disease they have been applied to balance disorders due to other pathologies, including vestibular disorders. As discussed in the section on vestibular function testing, recently there has been a proliferation of highly technical assessment tools for vestibular patients. Although these allow for quantification of deficits unique to patients with vestibular deficits, they are expensive. There are also many functional scales that have been developed to assess gait and balance abilities in the older adult population in hopes of identifying people at risk for falling who would benefit from intervention.⁴³ Many of these functional scales have also been applied to patients with vestibular disorders.

Romberg Test

The classic Romberg test was originally developed for assessment of ataxia in tabes dorsalis, a neurologic disease characterized by damage to the large proprioceptive fibers of the posterior lumbosacral roots, usually due to neurosyphilis. This disease results in loss of vibratory and position sense, parasthesias and areflexias in the lower extremities.⁴⁴ The Romberg test is performed by having the patient stand with feet parallel and together for 30 seconds, with the eyes open and then closed. Performance may be judged by the amount of time the position is held and/or the amount of body sway. Excessive sway, loss of balance or stepping during the test is considered abnormal. The amount of sway during the test can be quantified with a videocamera or forceplate (static posturography).⁴³

The Romberg has been commonly assumed to test the influence of the vestibular system on balance. However both the vestibular system and the somatosensory system provide accurate sensory information during test conditions, providing the presence of an intact central nervous system.⁴³ Considering the hierarchy of sensory use for balance, the only condition under which the vestibular system would be tested would be with peripheral neuropathy.

Notermans et al⁴⁵ explored the performance of patients with either cerebellar ataxia or sensory peripheral neuropathy on three modified forms of the Romberg test as a component of an ataxia test. Subjects were asked to maintain standing with their eyes closed for a maximum of 60 seconds under three conditions: with their feet 15 cm apart, close together and in tandem. Thirty-eight subjects completed the testing, 13 subjects with cerebellar ataxia (mean age 43 years) and 25 subjects with peripheral neuropathy (mean age 64 years). The subjects' performance was compared to test performance by 115 healthy adults (mean age 43) for control. Subjects with peripheral neuropathy demonstrated significantly lower stance times in all three positions than did control subjects or subjects with cerebellar ataxia. Both the control subjects and subjects with cerebellar ataxia maintained the first two postures, or classic Romberg, for the maximum of 60 seconds. The Romberg test was found sensitive to changes in gait ataxia in subjects with peripheral neuropathy.

Weber and Cass⁴⁶ studied the performance of patients with complaints of dizziness or imbalance on the Romberg test as part of a study of balance assessment. Fifty patients, aged 14-77 years, were referred for neuro-otological exam. Each subject underwent Romberg testing during standard vestibular testing. Fifty healthy adult

subjects served as controls. Each position was held for a maximum of 15 seconds. No difference was found between subjects with dizziness or imbalance and controls in their performance on the Romberg test.

Cohen et al⁴⁷ studied the performance of healthy adults of different age groups and vestibular deficient patients on the Romberg test as part of a study on the Clinical Test of Sensory Interaction and Balance (CTSIB). Forty-five healthy subjects were divided into 3 groups of 15 subjects each based on age (25-44years, 45-54 years and 65-84 years). Seventeen patients, aged 30-87 years, diagnosed with vestibular dysfunction also participated. Each subject was asked to maintain the classic Romberg, standing feet together, arms across the chest, for three trials of 30 seconds each. The authors found no difference among any of the four groups in their stance time on the Romberg test.

Bohannon et al⁴⁸ also evaluated the ability to maintain the Romberg test with eyes open and closed throughout the lifespan. Subjects included 184 healthy adult volunteers between 20 and 79 years of age, with 30 or more subjects in each decade of age. Subjects were asked to maintain the Romberg position with feet eight inches apart and then with their feet close together. Each position was maintained with both eyes open and closed for a maximum of 30 seconds. All subjects were able to maintain both these positions with their eyes open and closed for 30 seconds.

The Romberg test, originally developed for assessment of balance function in people with posterior column disease, can be quantified using forceplate and timing. Performance on the Romberg test does not deteriorate with healthy aging. It is sensitive in detecting balance deficits in people with peripheral neuropathy or posterior column

disease.⁴⁵ The Romberg test does not appear to be sensitive to balance deficits in people with vestibular disorders.

Fregly and Graybiel Ataxia Test Battery

Fregly and Graybiel's battery of ataxia tests expanded Romberg's original test. The purpose of their multidimensional ataxia test initially was to provide an evaluation of vestibular ataxia after flight.⁴⁹ The authors required a test that was more sensitive to changes in a subject's equilibrium response to rotational stimulation.⁵⁰ Initially the test was performed using "rails" however it was modified to include tests not requiring rails. The modified test was shown to discriminate between normal and abnormal equilibrium responses and was easier to administer in the clinic.⁵¹ The components of the revised ataxia test are listed in table 1. Normative data were collected during multiple trials with large numbers of healthy volunteers.

Fregly and Graybiel, 1968,⁵¹ reported normative standards of the revised ataxia battery not using rails. They recruited healthy volunteers from military and civilian scientific, medical, technical and administrative personnel, aviators, project astronaut candidates, students, housewives and senior citizens. Subjects included 2077 healthy males and 369 healthy females aged 17-71 years. Of those, 903 males and 178 females completed the entire test battery. The number of subjects completing each of the subtests depended on when the test was added to the test battery. Labyrinthine deficient individuals were recruited from neuro-otological patients with bilateral or unilateral vestibular hypofunction, Meniere's disease or vertigo. The subjects with labyrinthine deficit were in adequate or better health to participate in the testing. The group included

87 males aged 19-70 years and 53 females aged 20-70 years. All subjects completed the test battery described in table 1.

Males demonstrated higher scores on the sharpened Romberg and single limb stance tests than did females at all age levels. Performance on these tests began to decline at age 43 in males and age 30 in females. Age and gender differences in performance were similar in sharpened Romberg and single limb stance. All healthy subjects could obtain perfect scores on the walk on the floor eyes closed (WOFEC) and walk a line eyes closed test (WALEC) test. No significant age or gender differences were found in WOFEC performance.

All labyrinthine deficient subjects differed significantly in their performance of sharpened Romberg and single limb support with the eyes closed when compared with age-matched healthy subjects.⁵¹ None of the subjects with unilateral or bilateral vestibular hypofunction was able to meet the criterion for a scorable WALEC test. All attempts to perform tandem walking with eyes closed resulted in side stepping, veering or loss of balance. Their performance with eyes open on all ataxia tests, however, was equivalent to healthy “normal” subjects. They also demonstrated normal performance on the classic Romberg test eyes open and closed.

Fregly et al, 1972,⁵² introduced walk on floor eyes closed (WOFEC) as a new subtest of the ataxia test battery and a replacement for walk a line eyes closed (WALEC). The subjects who participated in this study included 287 healthy adult males aged 17-61 years and 100 females aged 18-65 years. Twenty-two men with labyrinthine deficit also completed the testing. Each subject underwent the complete ataxia test battery as described in table 1, with WALEC omitted. No significant difference in gender or age

was demonstrated in the performance of WOFEF. A greater percentage of females had imperfect scores on the test than their male counterparts. Males with labyrinthine deficits demonstrated significantly lower scores on WOFEF than did healthy males.

Test-retest reliability was measured by retesting healthy males on numerous occasions over periods ranging from weeks to months. Reliability was found to be high ($r=1.00$).⁵²

The authors concluded that the WOFEF is a worthy addition to the test battery. It has been demonstrated to selectively discriminate between subjects with and without labyrinthine deficits. It has the advantage over the other items of the test battery of being free of significant age and gender influences, at least in the age groups sampled.⁵²

Fregly et al revised their normative scores on the ataxia test battery in 1973.⁴⁹ The subjects included in this study were 1,055 physically fit males aged 16-60 years. Each subject underwent the ataxia test battery described in table 1, with the exception of WALEC. Subjects were divided into five age groups, to control for the negative influences of chronological age on performance of ataxia tests. The authors found that performance of all ataxia tests except WOFEF begin to decline within the 30-40 year age group rather than the 43-50 year age group as previously thought. The authors provide tables with percentile equivalents for each subtest the five new age groups. Using these tables clinicians can determine the scores at the fifth percentile which the authors have defined as the cut-off for normal. Subjects scoring less than the fifth percentile are considered to have abnormal postural control.

Takahashi et al⁵³ used Fregly and Graybiel's ataxia test to quantify postural stability in motion sickness. Subjects included 12 healthy adults aged 21-34. They were

asked to walk along a fixed course while wearing either horizontally or vertically reversing goggles. Subjects completed the ataxia test battery three times: before putting on the goggles, while walking with the goggles on, and at the end of the walk or when they stopped the walk due to severe sickness. The ataxia tests were able to distinguish between autonomic nervous symptoms and instability. Subjects who wore horizontally reversing goggles demonstrated significantly decreased scores on all tests at least once during the walk, however, performance on the ataxia test did not change significantly in subjects wearing vertical reversing goggles. The authors conclude based on response to the ataxia tests that vertical visual cues may not be important in producing spatial orientation.

Fregly and Graybiel's ataxia test battery is a reliable postural stability measurement. It has been shown sensitive in discriminating between normal and labyrinthine deficit subjects. The administration of the test is straightforward with grading criteria well documented in the literature. The test has several disadvantages. First, the test requires rails of varying sizes that may not be available in all clinics. Second, due to the influences of age and gender on the performance of the ataxia test battery, it is difficult to have a single value as a normative reference. This makes clinical interpretation more difficult. Third, the normative scores on the test were collected 30 years ago. Age and gender influences on these tests may have changed over time.

Functional Reach

Functional reach has been defined as "the maximal distance one can reach forward beyond arm's length, while maintaining a fixed base of support in the standing position."⁵⁴ The functional reach had been used previously by the automotive industry,

the National Highway Safety Administration and the National Aeronautics and Space Administration in the sitting position to ensure safety and functional utility of vehicle design.⁵⁴ Duncan and colleagues developed the standing functional reach test as a screening tool for balance problems in older adults.⁵⁵ The functional reach test is performed by having the subject stand with feet shoulder width apart and arm raised to 90° flexion. Subjects lean forward as far as possible, without moving the feet, keeping the arm parallel to the floor. The distance reached is measured and compared to age-referenced norms.⁵⁵

Duncan and colleagues investigated the reliability and validity of the functional reach test in 1990.⁵⁴ Subjects included 128 volunteers aged 29-87. Subjects were divided into three groups by age (20-40, 41-69, 70-87). Each subject performed three activities: center of pressure excursion measurement on a force platform, functional reach test measured using an electronic device, functional reach test measured using simple clinical apparatus of a leveled “yardstick” secured to the wall. The authors found that the functional reach test was strongly correlated with center of pressure excursion ($r=.71$). They also found that the electronic measure of the functional reach was strongly correlated with the yardstick (clinical) measure. Test-retest reliability and inter-observer reliability were high (ICC of .92 and .98 respectively). Performance on the functional reach test declines as age decreases. Height strongly influences performance on the reach test. Females also tend to have lower scores on the functional reach test than males however, when other factors, such as height, are controlled for these differences are not significant. Although the gender effect appears marginal compared to age and height, normative scores are provided based on age and gender but not for height.

Mann et al, 1996,⁵⁶ investigated the relationship between the functional reach test, single limb stance and the Dizziness Handicap Inventory (DHI) in patients with vestibular disorders. Their subjects included 28 patients aged 35-84 years old with diagnosed peripheral vestibular disorders. During the subjects initial physical therapy evaluation prior to beginning vestibular rehabilitation, the subjects completed the DHI, functional reach and single limb stance assessments. Duration of single limb stance was assessed using a static force platform. Subjects stood on their right foot with their arms folded across their chests, for three trials with a maximum of 300 seconds each. Functional reach was assessed using a 147-cm rule supported between two adjustable height supports. Subjects stood on the force platform and raised their arms to 90° of flexion so that the arm was parallel to the rule. Subjects were asked to reach forward as far as possible without taking a step. The test was repeated 5 times. Prior to testing, inter-rater reliability was assessed for both functional reach and single limb stance. Both tests were found to have high inter-rater reliability ($r=.89$) when assessed using 10 normal volunteers.

The authors found that patients with peripheral vestibular disorders demonstrated functional reach scores significantly lower than the normative scores established by Duncan.⁵⁶ Performance on single limb stance significantly decreased with age, although the authors did not find a significant difference in functional reach scores with age. There was a moderate but highly significant correlation found between functional reach and single limb stance. Of interest, the authors found that subjects who could not reach more than 30 cm could not stand on one leg for greater than 20 seconds. Subjects with scores on the Dizziness Handicap Inventory of greater than 50 out of a possible 100

demonstrated significantly poorer scores on functional reach than did subjects with DHI scores less than 50 out of a possible 100.

The functional reach test is a highly reliable and easily administered clinical test of balance. It has been shown to correlate strongly with both center of pressure evaluation⁵⁴ and single limb stance time.⁵⁶ It has the sensitivity to distinguish between subjects with and without vestibular disorders. Although functional reach did not directly correlate with the Dizziness Handicap Inventory, scores of subjects with greater perception of disability demonstrated poorer performance on the test.⁵⁶ This may provide helpful information for determining rehabilitation candidates. Caution must be exhibited when interpreting functional reach scores as significant height and age influences have been identified.⁵⁴ Although age and gender related normative values have been established, to date no values based on height have been published.

Berg Balance Scale

The Berg Balance Scale is a functional scale developed to identify balance problems in institutionalized older adults. The content of the scale was defined in three stages with input from multiple professionals. The final scale consists of 14 common tasks (table 2) which assess a subjects ability to obtain and maintain various postures or movements.⁵⁷ The tasks increase in complexity from sitting to standing to single limb stance. Each task is scored on an ordinal scale form 0-4, with a maximum score of 56. A score of four indicates that the movement is performed independently and the position is held for the prescribed time or performed within a set time frame. A score of zero indicates that the subject is unable to perform the movement. Criteria for scoring each is level is clearly defined for each task.⁵⁸ Internal consistency as measured by Cronbach's

alpha is high. Cronbach's alpha was calculated to be .96. To be clinically useful an alpha of greater than .90 is desirable. This indicates that the scale is measuring only one concept but providing more information on balance than one item would.⁵⁷ The Berg balance scale has been used to assess balance function in older adults with neurologic dysfunction and other causes of balance impairments.⁵⁸

To assess reliability of the balance scale, Berg et al⁵⁷ videotaped 14 patients with varying degrees of balance impairments performing the 16 movements on the initial scale. The test was administered by a physical therapist. Five physical therapists experienced in geriatric rehabilitation viewed the videotape and scored the performance. They received no specific training and were allowed to view the tape only once. Intraclass correlation coefficients (ICC) for individual items ranged from .71 to .99. The ICC for the total score was .98, demonstrating a high degree of agreement among the raters in scoring the items of the balance scale. To assess intra-rater reliability four of the therapists were invited to return one week later and view the same videotapes. The ICC was calculated to be .99 for the total balance score and ranged from .71 to .99 for individual items. In the preliminary study, the authors found that the Berg balance scale demonstrated significant correlation with ambulatory status.

Berg et al⁵⁹ investigated the validity of the balance scale by assessing correlation with other functional scales in subjects following acute stroke, nursing home residents and community dwelling elderly with balance disorders. Subjects included 113 residents of a nursing home mean age 83.5 years, 70 stroke patients mean age 71.6 years and 31 community dwelling elderly mean age 83.0. The authors found good correlation between the balance scale and the Barthel Index ($r=.80$) and Fugl Meyer scores ($r=.62-.90$). There

was a strong correlation between balance scale score and disposition of stroke patients 12 weeks after the initial episode. Based on clinical observation and fall history the authors specified that a score of 45 out of a possible 56 is the cut off between those individuals who are safe in ambulation and those who require intervention regarding supervision or assistive device.

Berg et al⁶⁰ assessed reliability and internal consistency of the balance scale using the subjects described in the previous study. Thirty-two individual raters assessed 35 stroke patients and 28 elderly residents using the balance scale. Each subject was rated twice within one week by random pairs of raters to assess inter-rater reliability. The ICC with all subjects included was 0.98. When calculated for the elderly residents alone the ICC was 0.92. When calculated for the stroke patients alone the ICC was 0.98. To assess for intra-rater reliability seven raters evaluated 24 stable subjects twice, one week apart. The ICC for all subjects was 0.97, whereas elderly residents demonstrated an ICC of 0.91 and stroke patients an ICC of 0.99. The authors conclude that the Berg balance scale demonstrates high reliability in a variety of clinical and home settings by raters who were provided with minimal training in the administration of the test.

Bogle Thorbahn and Newton⁶¹ investigated the predictive value of the Berg balance scale in assessing fall risk in community dwelling older adults. Subjects included 71 volunteers from 2 life care communities, with a mean age of 79.2 years. The authors calculated inter-rater reliability by having every fourth subject repeat the test with another rater, after a brief rest. Seventeen subjects were retested. The authors used Spearman rho to calculate reliability and found high reliability ($r_s = .88$). The authors found a

specificity of 96% and a sensitivity of 53%, using Berg's cutoff score of 45. The authors also found the subjects who fell most frequently scored closer to the cutoff.

The Berg balance scale has been shown to be a reliable and valid functional scale in the older adult population. It has shown strong correlation with other functional scales such as the Fugl-Meyer assessment and the Barthel Index.⁵⁹ The Berg balance scale is primarily a scale of static balance with eyes open and head stable position. The tasks included in the scale are not typically those that challenge patients with vestibular deficits. Although no published study has reported the performance of patients with vestibular dysfunction on the Berg balance scale, personal clinical experience has demonstrated high scores in most subjects. Subjects demonstrate difficulty on only two of the tasks: standing in tandem and single limb stance. The Berg balance test was designed to evaluate fall risk and balance impairment in older adults. Falls occur infrequently in patients with vestibular disorders, so clinicians are not as concerned with the risk of falling as with quantification of postural instability. The Berg balance scale is a useful tool in evaluating balance in the older adult at risk for falls, but it does not demonstrate the sensitivity or the essential tasks required in evaluating patients with vestibular dysfunction.

Performance-Oriented Assessment of Balance

The Performance Oriented Mobility Assessment (POMA) was developed by Tinetti et al⁶² to evaluate mobility status in older adults at risk for falling. The POMA is a 16 item functional scale that evaluates gait and balance tasks (see table 3). Each item is graded on either a three level ordinal scale or a dichotomous scale. Tinetti developed the gait and mobility scale as part of a multifactorial evaluation to identify chronic

characteristics associated with falling.⁶³ In addition to the gait and mobility assessment Tinetti et al⁶³ evaluated mental status, morale, vision, hearing, blood pressure, medications and ADL status.

Tinetti et al⁶³ performed assessments on subjects admitted for the first time to intermediate care facilities. They evaluated 79 subjects over the age of 60 years (mean age 79 years). Subjects were followed prospectively after admission to the intermediate care residence to determine which subjects fell two or more times within the first three months after admission. The authors defined a fall as an “unintentional change in position, occurring under circumstances in which a fit person could have resisted the external hazard.” The 25 subjects who fell at least twice during the first three months after admission constituted the recurrent faller group. Almost all of the recurrent fallers had poor back flexibility, decreased lower extremity strength, poor distant vision and symptoms of dizziness and imbalance when turning or extending the neck. The authors found that the gait and balance measures were the most helpful in identifying recurrent fallers. The mean total balance and gait (POMA) score for recurrent fallers was 14 out of a possible 28 (+/- 6) as opposed to 21 out of a possible 28 (+/- 4) for those who fell once or not at all.

Cipriany et al⁶⁴ examined the inter-rater reliability of the balance portion of the POMA when performed by novice and experienced clinicians. The study was completed in 2 phases. In phase one, 26 Skilled Nursing Facility (SNF) residents aged 66-90 years were evaluated on site by three physical therapy students during a six week affiliation. The students had completed training using videotaped administration of the POMA with guidance by an experienced physical therapist. Fair to excellent inter-rater

reliability of all items was found between the three students using the kappa statistic ($k = .57 - .82$). In phase two, nine raters participated: five physical therapists with less than six years of experience, a physical therapist assistant with one year experience and the three physical therapy students who participated in phase one. All raters in phase two completed training similar to that given in phase one. Administration of the POMA by the primary investigator was videotaped. The test was administered to 24 hospital patients and five SNF residents aged 60-92 years. The videotaped sessions were scored independently by each of the nine raters within two months of data collection. Inter-rater reliability between the nine raters was fair to good when calculated with the kappa statistic ($k = .47 - .69$) in five of the eight subtests. The percent agreement was not any greater for the most experienced group than the lesser-experienced group for any of the items.

The Performance Oriented Mobility Assessment has been demonstrated to have fair to good reliability when performed by clinicians with varying experience levels.⁶⁴ It is sensitive in identifying institutionalized older adults at increased risk for falls, however it may not be sensitive enough to detect the smaller change in performance needed to document improvement with intervention.⁶⁵ As the scale was developed to detect fall risk in institutionalized older adults, the level of the tasks is not sufficiently challenging to assess postural stability in community dwelling older adults or patients with vestibular disorders.

Stepping Test

The Unterberger or Fukuda stepping test evaluates postural stability or vestibulospinal function with self-initiated movement of marching in place for 50-100

steps with the eyes closed. Excursion of movement more than 50 cm or rotation of greater than 30 is considered abnormal (see figure 10).⁶⁶ The test has been clinically assumed to indicate peripheral vestibular hypofunction with the direction of rotation indicating the side of lesion.⁶⁶

Hickey et al⁶⁷ evaluated the correlation between electronystagmography (ENG) test results and Fukuda stepping test results. Subjects included 49 normal subjects aged 21-60 years and 26 patients with poorly compensated peripheral vestibular lesions on bithermal calorics. Subjects were asked to march in place for 100 steps with their arms extended and eyes closed. The authors found no correlation between canal paresis and angle of rotation or distance traveled. No correlation was also found between the side of canal paresis and the direction of rotation. There was no significant difference in angle of rotation, angle of displacement or distance traveled between normal subjects and patients with peripheral vestibular lesions.

Gordon et al 1995⁶⁸ attempted to evaluate the degree to which the stepping test isolates vestibulospinal function. Seven normal subjects ambulated on a circular treadmill for 2 hours, while remaining spatially stationary. As the subjects were spatially stationary, there was no relevant vestibular stimulation. Subjects were asked to march in place for 50 steps with arms extended and eyes closed before and after ambulating on the treadmill. Three of the seven subjects exhibited inconsistent direction of rotation prior to ambulation. After getting off the treadmill, all subjects demonstrated rotation in the same direction as their walking on the treadmill. The author's suggest that the somatosensory or locomotor stimulation from ambulation on the treadmill caused more consistent and marked rotation in the stepping test than that caused by physiologic or pathologic

vestibular stimuli. These findings discredit or negate the specificity of the stepping test as an indicator of vestibulospinal function and emphasize the role of somatosensory signals in stepping in place with the eyes closed.

The Fukuda or Unterberger stepping tests have not been found to be a reliable or valid measurement tool.^{67,68} Results of testing can be highly variable between trials without changes in subject or test conditions. There is no correlation between vestibular dysfunction or stimulation and angle of rotation or distance traveled. The stepping test appears to be more an indication of somatosensory function than vestibular function.⁶⁸

Clinical Test of Sensory Interaction In Balance

The Clinical Test Of Sensory Interaction in Balance (CTSIB) was developed by Shumway-Cook and Horak⁶⁹ to test the ability of patients to use sensory inputs for balance. The test is modeled after computerized dynamic posturography and was developed as a low cost alternative to CDP in the clinic. The subjects maintain a standing position for 30 seconds under six different conditions (see figure 11).⁷⁰ In the first two conditions the subjects maintain normal stance with the eyes open and closed. To provide visually inaccurate sensation in condition three, the subject stands with a dome, made from a Japanese lantern, over their head. Conditions four, five and six require the subject to maintain standing on viscoelastic foam to provide inaccurate somatosensory information, with the eyes open, the eyes closed and with the visual conflict dome. The subject performs three trials of each condition for a maximum of 30 seconds each (see table 4). Attempts to further quantify the CTSIB have been developed using static force platforms measuring postural sway. The inability to maintain stance during conditions five and/or six for 30 seconds indicates vestibular dysfunction.^{69,70}

Cohen et al⁷¹ investigated the performance of neurologically asymptomatic adults and patients with vestibular disorders on the CTSIB. Inter-rater reliability and test-retest reliability were evaluated during their pilot study. Two investigators simultaneously rated five asymptomatic physical therapy students (aged 20-24 years old) on the CTSIB for inter-rater reliability. The five subjects were evaluated twice by the same investigator for test-retest reliability. The authors found high inter-rater and test retest reliability using the Pearson product-moment correlation coefficient ($r = .99$). Three groups of 15 neurologically asymptomatic subjects participated in the main study. Each group represented a different age group (25-44 years, 45-64 years and 65-84 years). A fourth group was comprised of 17 patients aged 30-87 years diagnosed with vestibular disorders. All subjects underwent the six conditions of the CTSIB described in figure 11. Three trials for a maximum of 30 seconds each were completed for each condition. All subjects could maintain standing for 30 seconds on conditions one through three. The two younger groups were able to maintain upright stance for the maximum of 30 seconds for conditions four, five and six. Greater variability in stance time on conditions four, five and six was demonstrated by the older adult and the vestibular impaired groups. Both groups tended to demonstrate improved scores on successive trials. No differences were found between vestibularly impaired subjects and age matched asymptomatic subjects in performance time on condition four. There was, however, a significant difference between age matched subjects on conditions five and six. The authors conclude that although the CTSIB does not specify the exact nature of a subjects' balance problem, it is sensitive in isolating subjects with vestibular disorders.

Weber and Cass⁴⁶ compared the performance of 50 patients (aged 14-77 years), with complaints of dizziness and imbalance, on the CTSIB and CDP. Each patient performed the tests as part of the office and laboratory exam to investigate their complaints of dizziness and imbalance. The CTSIB included only conditions one, two, four and five. Each subject maintained the Romberg position with eyes open and closed, then stood on medium density viscoelastic foam, eyes open and closed. The test was considered abnormal if the subjects fell within 15 seconds. Subjects completed the standard Sensory Organization portion of CDP as defined by NeuroCom International (Clackamas, OR). Trials were considered abnormal if the subjects fell, needed to take a step or exhibited sway greater than the normal range of sway established by NeuroCom. Using the dichotomous rating scale the authors found a significant relationship between results of CTSIB and CDP for both condition five and the total score, using the Chi-square statistic. The sensitivity of condition five CTSIB (using CDP as the gold standard) in identifying subjects with vestibular dysfunction was 95%. The sensitivity of the composite CTSIB score was 90.5%. The specificity of condition five and overall score of CTSIB in identifying those subjects without vestibular dysfunction was 90%. No significant correlation was found between vestibular laboratory tests (ENG and RVT) and either CTSIB or CDP. The authors conclude that CTSIB is a clinical test that isolates vestibulospinal function similar to the sensory organization test. It is a rapid inexpensive test that provides useful clinical information.

El-Kashlan et al³⁰ also compared performance on the CTSIB and the sensory organization portion of the computerized dynamic posturography. Two groups of subjects were included in this study. Group one included 69 asymptomatic older adults

aged 20-79 years. Group two included 35 adults aged 20-70 years with persistent vestibular disorders. Subjects completed the CTSIB as previously described (figure 11). Each subject completed three trials of a maximum of 30 seconds for each condition. The average of the three trials for each of the six conditions was added for a maximum possible score of 180. The sensory organization portion of the CDP was completed as per the protocol developed by NeuroCom International. The authors used a composite score based on performance of all six conditions for a maximum of 1000. A score below the fifth percentile (675) was defined as abnormal postural control. Good correlation was demonstrated between CTSIB and CDP total scores using Pearson Product Moment Correlation coefficient ($r=.41-.89$). Cohens k calculated between CTSIB and CDP total scores was .80 indicating strong agreement. The specificity of the CTSIB was found to be 87% and the sensitivity was 60% (using the SOT of CDP as the reference). The CTSIB was effective in identifying subjects with normal postural control abilities, yet had a poor ability to detect abnormal postural control. The CTSIB was significantly less sensitive in detecting more subtle patterns of balance dysfunction.

The CTSIB is a reliable and inexpensive tool for use in clinical assessment of postural stability. Test-retest and inter-rater reliability has been shown to be high when tested with normal subjects.⁷¹ It has been shown specific in identifying those with normal postural stability but has demonstrated mixed sensitivity in identifying those with vestibular deficits.^{30,46,71} Differences in scoring criteria may account for the variability in sensitivity found in these studies. Although the developers of the test state that falls on condition five are indicative of vestibular dysfunction, no one investigated the ability of the test to distinguish between balance deficits seen with vestibular disorders and those

seen with other neurologic disorders. The CTSIB is an inexpensive, reliable balance assessment that appears to give general information about a person's ability to balance with various sensory inputs. It is unable to detect subtle patterns of balance dysfunction or to isolate the etiology of the balance dysfunction.

Gait Assessment

Assessment of mobility skills can be either quantitative or qualitative. Several clinical measures have been developed to document both the quality of movement and the temporal-spatial characteristics. The assessment tools range from the highly technical involving EMG and motion analysis to purely observational and descriptive. Although not developed to assess mobility skills in patients with vestibular disorders, many of these techniques have been applied to that population.

Borello-France et al²³ recommend descriptive observational gait analysis during a variety of tasks requiring various head and body movements and various sensory inputs (table 5). Documentation should include gait deviations, movement strategies utilized and abnormal sensations of movement. The time required to complete a task and magnitude of sway can further quantify function. Videotaping the gait activities can also help to document improvement over time. Although the authors did not provide any objective measurements, they did indicate that common gait deviations associated with vestibular dysfunction include widened base of support, decreased head and trunk movement, decreased gait speed and veering right and left.²³

The Gait Abnormality Rating Scale (GARS) was developed by Wolfson et al.⁷² The GARS is a 16-item functional gait scale that includes items pertaining to variability of gait, posture, stance time and staggering (table 6).⁷³ The GARS was developed for

rating qualitative gait abnormalities from videotaped ambulation. It allows for quantification and documentation of common gait deviations. It was originally intended as a simple clinical gait assessment for subjects at increased risk of falling.⁷⁴ Subjects walk at a self-selected pace while being videotaped. The videotape is viewed in slow motion and is rated for the presence and severity of 16 gait deficits. The gait deficits are rated on a four level ordinal scale (0 = normal, 3= severe impairment).

Wolfson et al⁷³ investigated the reliability and validity of the GARS. Subjects included 49 nursing home residents, 27 residents with a history of two or more unexplained falls within the previous year and 22 nonfallers as the control group. To assess stride length and gait velocity, subjects were videotaped ambulating for ten meters with chalk attached to the heel of their shoe. Stride length was measured from the chalk marks. Gait velocity was calculated by timing the duration of ambulation from the videotape. Raters completed training involving the viewing of pilot study videotapes in slow motion and discussing the rating scale to come to consensus. Two judges viewed the videotapes independently and rated the ambulation using the Gait Abnormality Rating Scale. The inter-rater reliability of the individual and total GARS scores was significant using Spearman rank-order correlation ($r = .475 - .954$, $p < .001 - .0001$). Highly significant correlation was found between stride length and GARS total score for both fallers and nonfallers ($r = -.82, -.79$). Stride length, walking velocity and GARS scores were significantly impaired in nursing home residents with a history of falls, as compared to controls.

In their original article, the developers of the GARS suggest that the test be streamlined to seven items on the basis of reliability of individual items and the ability to

discriminate between fallers and nonfallers. Van Swearingen et al⁷⁴ investigated the modified Gait Abnormality Rating Scale (GARS-M, table 7) in community dwelling older adults. Their three purposes were: to determine inter- and intra-rater reliability, to correlate GARS-M scores with stride length and gait speed and to examine the ability of the GARS-M to distinguish between community dwelling older adults with and without a risk for falling. Subjects included 52 community dwelling frail older male veterans referred for evaluation. Their mean age was 74.8 years. All subjects ambulated independently without assistive device. Subjects were divided into two groups based on the number of falls in the previous year. A fall was defined as “any unexpected loss of balance resulting in coming to rest with the ground or floor.”⁷⁴ Subjects with two or more falls in the previous year constituted the faller group. Subjects were videotaped walking at a self-selected pace. The videotape was analyzed in slow motion for determination of GARS-M scores, stride length and walking speed. Training was provided prior to viewing the videotape. Stride length and walking speed were determined from a timed walk down a six meter paper walkway with a marker attached to the heel using a technique described by Cerny⁷⁵ Three physical therapist raters independently determined the GARS-M score. The first 23 subjects were rated by the three therapists on two separate occasions seven to ten days apart to determine reliability. The raters experience level varied from less than two years to 14 years. Moderate to substantial agreement was demonstrated for intra-rater reliability of individual items using the kappa statistic for the three raters ($\kappa = .493, .583, .676$). Intraclass correlation coefficient demonstrated excellent intra-rater reliability of GARS-M total scores (ICC = .968, .950, .984). Inter-rater reliability of individual items was found to be moderate

using the kappa ($k = .485 - .635$). When inter-rater reliability of individual items was calculated between the two experienced therapists only, kappa statistics were much higher ($k = .789, .886$). Intraclass correlation coefficients for total GARS-M score demonstrated high inter-rater reliability ($ICC = .968, .975$). The GARS-M score was shown to have significant correlation with stride length and gait speed. The GARS-M score was able to accurately distinguish between subjects with and without a history of falling. The authors conclude that the GARS-M is a reliable and valid measurement of gait abnormalities associated with increased risk of falling in community dwelling older adults.⁷⁴

Whipple and Wolfson⁷⁶ investigated the performance of institutionalized older adults on the Gait Abnormality Rating Scale and other measures of gait and balance. Forty nursing home residents were divided into two groups based on their history of falling. Twenty-two subjects (mean age 84 years) had sustained at least two unexplained falls within the previous year and constituted the faller group. Eighteen subjects (mean age 81 years) had no history of falling and constituted the nonfaller group. Subjects were videotaped ambulating at their self-selected speed on a ten-meter walkway. Pieces of chalk were adhered to the heels of each subject's shoes. Stride length and velocity were calculated from chalk imprints and time of ambulation calculated when the videotape was replayed. Two examiners assigned GARS scores while viewing the videotape at slow motion. The authors found that stride length and velocity were significantly decreased in the faller group, compared with nonfallers. Significantly greater impairments were demonstrated by the faller group on GARS individual and total score than the nonfaller group. The total GARS score correlated significantly with stride length for both groups.⁷⁶

The Gait Abnormality Rating Scale has been found to be a reliable functional scale in quantifying gait abnormalities associated with increased risk of falling in older adults. The use of this measurement has not been reported in subjects with vestibular disorders. Although it attempts to quantify common gait deviations, it does not assess the gait tasks that reveal abnormalities in vestibular deficits. Wolfson and Whipple⁷⁶ report preliminary results of performance of community dwelling older adults, with and without a history of falling, on the GARS. Composite GARS scores, stride length and gait velocity were unable to distinguish between community dwelling fallers and nonfallers. If the test is insensitive in distinguishing gait abnormalities in community dwelling older adults it would probably lack the sensitivity in distinguishing gait abnormalities in vestibular deficits where gait abnormalities are more subtle.

Krebs et al⁷⁷ evaluated gait in eight patients with bilateral vestibular hypofunction. Subjects underwent either eight weeks of vestibular rehabilitation followed by eight weeks of home exercise or eight weeks of outpatient physical therapy followed by eight weeks of vestibular rehabilitation. Kinetic and kinematic gait analyses were performed before intervention, at eight weeks after starting the program and after completion of the 16 weeks. Subjects performed three ambulation tasks: free gait, paced gait at 120 steps/minute and ascending steps. The authors measured average forward velocity, double stance time and center of pressure. Free gait velocity improved from 89.8 cm/sec to 96.7 cm/sec at eight weeks and 103.2 cm/sec at 16 weeks in subjects who had received vestibular rehabilitation. Subjects who had received vestibular rehabilitation demonstrated significantly greater increases in free gait velocity than those who received outpatient physical therapy. The free gait velocities demonstrated by subjects with

bilateral vestibular hypofunction were significantly lower than their paced gait velocities. Subjects were capable of faster walking speeds as demonstrated during the paced trials but preferred slower speeds.⁷⁷

Kubo et al⁷⁸ performed gait analysis on eight healthy young males (aged 21-36 years) before and after ice water caloric stimulation to the left ear. This unilateral ice water stimulation simulates an acute vestibular hypofunction. Three-dimensional movements of the head, neck and trunk were recorded with two infrared cameras. Angular and translational movements were recorded from eight markers on the body: external canthus, external auditory meatus, C₇, acromial process, greater trochanter, knee, ankle and lateral fifth metatarsal. Subjects were asked to ambulate in place and on treadmill before caloric irrigation and within 154 seconds following. Medial and lateral movements of the hip joint were significantly greater following caloric stimulation, while the head and neck movements were within pre-stimulus level. This increased hip excursion after caloric stimulation supports the theory of reliance on a hip balance strategy for locomotion. There was a slight decrease in stride length and increase in gait cycle duration following caloric stimulation.

Ishikawa et al⁷⁹ performed gait analysis using EMG and foot switches to explore differences in gait parameters between central and peripheral vestibular lesions. Thirty-one subjects with peripheral vestibular lesions and ten subjects with central vestibular lesions participated. Their performance was compared with 14 healthy adults who served as controls. Foot switches were placed below the calcaneal tubercle and under the first metatarsal head. Surface EMG activity was measured from the anterior tibialis and lateral head of the gastrocnemius. The authors measured seven parameters including time

from hindfoot strike to forefoot strike, time from hindfoot off to forefoot off, duration of stance, duration of swing, duration of double support, location of peak monophasic contraction of the gastrocnemius during stance and the contraction of the anterior tibialis after the initiation of swing. Thirty-eight percent of the subjects with peripheral vestibular dysfunction demonstrated gait abnormalities as opposed to 61% of the group with central vestibular disorders. The greatest portion of subjects in both groups demonstrated abnormally increased time from hindfoot strike to forefoot strike. Parameters indicative of central vestibular lesions included increased stance, decreased swing and increased double support time.⁷⁹

Several researchers have investigated the stabilization of head movements during locomotion in vestibular dysfunction. Pozzo et al⁸⁰ asked normal subjects (n = 10, aged 20-45 years) and subjects with bilateral vestibular hypofunction, secondary to gentamicin ototoxicity (n = 8, aged 35-76 years), to perform two locomotor tasks. Subjects were asked to ambulate at a self-paced speed and to hop on one foot in both light and darkness. Head and body kinematics were studied. Ten reflective markers were placed on the head, neck, trunk, upper and lower extremities. Linear and angular head velocity was measured. Subjects with bilateral vestibular deficits demonstrated shorter stride lengths than normal subjects. They demonstrated greater rigidity in the head, trunk and upper extremity. Normal subjects were able to align their head in relation to earth's horizontal accurately and consistently trial after trial. Subjects with vestibular dysfunction were unable to stabilize their head and demonstrated greater variability. They related that the head postures adopted were necessary to improve visual input needed for balance. The authors suggest that the true purpose of these head positions was to anchor vision to

surrounding fixed landmarks in the visual field, providing spatial reference to assist in controlling balance.⁸⁰

Taguchi et al⁸¹ observed head movements as measured by accelerometer while subjects were marching in place. Subjects included ten normal subjects (aged 18-30 years), and 22 subjects with unilateral peripheral vestibular dysfunction. Subjects were asked to march in place at four speeds with the eyes open and then closed. The speeds were regulated through the rhythm given through a headphone. Three-dimensional accelerometers were attached to the top of the head to record head movements in lateral, anteroposterior and vertical directions. Subjects with peripheral vestibular disorders demonstrated significantly greater head movements in all directions than normal subjects, especially with the eyes closed.

Gait analysis in vestibular deficits has been performed through qualitative observational gait analysis, ink and paper, EMG and heel switches and motion analysis of either head, trunk or extremity movements. There appears to be agreement that subjects with vestibular disorders display shorter stride length, decreased velocity and increased medial-lateral hip displacement when compared to normative values. Although these differences have been documented, greater deviations may be seen with tasks requiring head and body turns, manipulating objects or altered sensory inputs. To date no functional gait measures have been applied to patients with vestibular disorders. A reliable functional gait assessment that includes measurement of the gait abnormalities seen in vestibular disorders would be useful.

Dynamic Gait Index

The Dynamic Gait Index (DGI) was developed in 1995 to assess dynamic postural stability in patients with vestibular disorders or the older adult at risk for falling. The scale was developed for use in clinical settings to quantify aspects of gait influenced by vestibular dysfunction. The dynamic gait index consists of eight ambulation tasks with varying demands such as walking at different speeds, walking with head turns, ambulating over and around obstacles, ascending and descending stairs and making quick turns. Each item is scored on a four level ordinal scale (see Table 8). The maximum score is 24. A score of 18 or less indicates increased risk of falling.⁸²

To ensure accuracy of the results of the dynamic gait index the patient or subject should meet several inclusion criteria. They need to ambulate at least 20 feet with or without mechanical or physical assistance. They need to have adequate endurance to allow repetitive trials of ambulation, with rests between trials as needed. Adequate cognition is required to understand and follow two step commands.

The mini mental status examination (MMSE) is a 30-item test originally designed to detect patients with cognitive impairment in a psychiatric population. This verbally administered screening tool assesses the patients' orientation, memory, attention, ability to follow commands and language skills.⁸³ The MMSE has been shown to have high inter-rater ($r = .95$) and intra-rater ($r = .93$) reliability.⁸⁴ Significant correlation has been demonstrated between the MMSE and other test of neuropathology.⁸³ A score of less than 24 out of a possible 30 is considered to be indicative of cognitive dysfunction.

Shumway-Cook et al⁸⁵ utilized the DGI as an outcome measure in a prospective clinical investigation that examined the effects of exercise on balance and mobility in

community dwelling older adults with a history of falling. During a pilot study they initially established reliability using a sample of five community dwelling older adults with varying balance abilities. Five therapists, trained in the administration of the dynamic gait index, evaluated the subjects on the DGI. Two of the subjects repeated the test one-week later to determine test-retest reliability. Excellent inter-rater reliability (.96) was found using the ratio of subject variability to total variability. Test-retest reliability was also excellent at .98.

Following the pilot study, Shumway-Cook et al studied 84 community dwelling older adults aged 62-97 with a self-reported history of two or more falls in the previous six months. These constituted the exercise group. The exercise group was divided into two groups using a post-hoc analysis of compliance with the exercise program. A nonequivalent control group of 21 volunteers (aged 66-97 years) was used. These subjects also had a history of two or more falls in the previous six months but received no intervention. All subjects underwent a balance and mobility assessment including Mini Mental Test, Balance Self Perceptions Test, Berg Balance Scale, Three-minute walk test, Performance Oriented Mobility Assessment and DGI. Subjects were evaluated prior to initiating the exercise and just prior to discharge, eight to twelve weeks later. The control group was reassessed eight weeks following the initial evaluation. Both exercise groups demonstrated significant improvement on the DGI when compared with the control group. The DGI was the only balance or mobility scale that demonstrated significant differences between the partially and fully compliant exercise groups.

Shumway-Cook et al⁸⁶ evaluated the DGI as part of a study to develop a means to quantify fall risk among community dwelling older adults. The subjects were 44

volunteers over the age of 65 years, without neurological or musculoskeletal disorders that would account for imbalance or falls. Subjects with two or more unexplained falls within the previous six months were classified as fallers. Subjects with one fall in the previous six months were excluded from the study. The nonfaller group included 22 older adults age 65-86 years (mean age 74.6 years). The faller group included 21 older adults aged 65-94 years (mean age 77.6 years). All subjects underwent balance and mobility assessments including the Balance Self-Perceptions Test, Berg Balance Scale, DGI, self paced and fast gait. The two groups demonstrated significant differences on performance of the Berg Balance Scale, the DGI, use of an assistive device, the Balance Self-Perceptions Test and history of imbalance. The highest correlations between risk factors were between the DGI and the Balance self-perceptions test (.76) and between the Berg balance scale and the Balance self-perceptions test (.76). Using a cut-off score of 19 as being abnormal, the authors found that the DGI correctly identified fallers (sensitivity) 59% of the time and correctly identified nonfallers (specificity) 64 % of the time.

No reports of the use of the dynamic gait index in patients with vestibular disorders are currently found in literature. The DGI has been shown to have excellent reliability in older adults. As it contains many of the gait tasks that are impaired in patients with vestibular disorders it may be a useful addition to the functional assessment of balance and mobility in the vestibular deficient patient.

Reliability

The reliability of a measurement is the consistency or reproducibility of that measurement.⁸⁷ It allows you to determine how confident you can be that the changes seen in a measurement actually represent changes in the item of interest and therefore the

clinical relevance of the measurement.⁸⁸ Every measurement includes some degree of error. The reliability of a measurement indicates how much of a measurement is true and how much is error. Because the true portion of a measurement cannot be determined directly, we examine reliability using the stability or agreement of different sets of measurement.⁸⁷

There are three potential sources of error in a measurement. First, there may be flaws in the instrument.⁸⁷ Grading criteria that are inadequately defined may lead to difficulty in assigning grades to different behaviors and may lead to variations in interpretation of criteria. Second, there may be a lack of consistency in the variable of interest in the population being studied.⁸⁷ If the variable of interest varies significantly from moment to moment, any measurement of that variable will never demonstrate consistency. Third, there may be errors made by the person taking measurements.⁸⁷ Lack of precision in applying instruments or attention paid to subtle differences in grading definitions can adversely effect outcomes. The degree to which any of these errors is present depends on the measurement tool, the population studied and the person administering the tool.

Several forms of reliability can be assessed. The different forms of reliability measure the agreement of different sets of measurement based on the three sources of error mentioned above. Inter-rater reliability measures the agreement of measurements taken by different examiners. Intra-rater reliability measures the agreement in measurement over time when one person takes repeated measurements. Test-retest reliability examines the stability of the test over time by comparing repeated measurements separated by time.⁸⁷

Although reliability has been demonstrated for the Dynamic Gait Index, it was assessed using a population of older adults with varying degrees of balance dysfunction. The purpose of this study was to examine the inter-rater and intra-rater reliability of the Dynamic Gait Index when used with patients with vestibular disorders. Rothstein⁸⁷ states that reliability studies should be specific to the population of interest, as the variability of subjects on test performance may influence the reliability of the measure. Because subjects with vestibular dysfunction have demonstrated increased variability in gait performance as compared to normals,⁸⁰ reliability needs to be demonstrated in this population. The Dynamic Gait Index evaluates gait tasks that are difficult for patients with vestibular disorders. If the DGI is shown reliable in subjects with vestibular disorder, it may provide an inexpensive clinical tool that measures dynamic postural stability. Such a tool would serve three important functions: it would be useful in determining efficacy of treatment, would allow patients to be categorized into severity of involvement which would allow for planning of treatment strategies in the future and would designate patients who would best benefit from vestibular rehabilitation.

Methods

This use of human subjects in this study was approved by Old Dominion University's Human Subjects Institutional Review Board. Subjects were recruited from patients referred for vestibular rehabilitation at Bon Secours DePaul Medical Center in Norfolk, Virginia. All patients meeting the following inclusion criteria between 4/98 and 8/98 were invited to participate: over 18 years of age, Mini Mental Status Exam (MMSE) score greater than 24, no neuromuscular disorder that would impair their ability to complete the Dynamic Gait Index, and ability to give informed consent. Prior to referral for vestibular rehabilitation, each subject underwent an neuro-otologic examination and vestibular testing. Vestibular testing was comprised of ENG, rotational chair testing and computerized dynamic posturography. Each subject was given a vestibular diagnosis by the neuro-otologist following testing. Vestibular diagnoses included unilateral vestibular hypofunction, bilateral vestibular hypofunction, cervical vertigo, central vertigo and visual dependence.

The two raters in the study were physical therapists each with over ten years of experience in physical therapy. Both raters had several years experience in the assessment and treatment of patients with vestibular and balance dysfunction. Prior to the study, the raters were briefly trained in administration of the Dynamic Gait Index by reviewing the test items and grading criteria. The primary investigator provided standardized verbal instructions and guarding of all subjects.

Following giving informed consent, each subject completed a health questionnaire to screen for neuromuscular or orthopedic disorders that would impair their ability to complete the Dynamic Gait Index. The Mini Mental Status Exam was administered to

insure that all subjects would have adequate cognitive functioning to follow the commands used in the study and to give informed consent. Subjects completed the Dizziness Handicap Inventory as a measure of self-perception of disability. The inventory was completed during the initial vestibular testing.

The subjects completed the Dynamic Gait Index twice during either their first or second treatment session depending on available time to administer the test and availability of raters. Each subject was given the same verbal instructions and proceeded to complete DGI tasks one (gait level surfaces) through eight (walking up and down stairs) as well as he or she could (see table 8). As the subject completed each task, he or she was given a rating that ranged from zero (severe impairment) to three (normal).

To assess intra-rater reliability the test was administered twice by the primary investigator, at the beginning and end of the hour-long session. To assess inter-rater reliability the Dynamic Gait Index was scored concurrently by both raters once during the session. Raters were blind to each other's results. Between administration of the tests the subject completed the subjective portion of their physical therapy evaluation or completed treatment activities with low physical demands such as vestibular stimulation exercise or static balance activities.

To evaluate for inter-rater and intra-rater reliability the amount of agreement was determined for individual items of the Dynamic Gait Index between raters and between trials. Percent agreement and Cohen's kappa coefficient were calculated for each item and the kappa values were averaged to give a composite reliability score. The kappa statistic is a means of determining percent agreement in categorical data while accounting for agreement that is due to chance.⁸⁹ Kappa is interpreted as the amount of agreement

among raters after chance agreement has been removed. Three assumptions must be met prior to using kappa: the subjects to be rated must be independent of each other, the raters must score the subjects independently and the rating categories must be mutually exhaustive and exclusive.⁹⁰ A kappa value of one indicates perfect agreement, while a value of zero indicates agreement entirely due to chance. It is generally accepted that a kappa value of greater than .80 is excellent, between .60 and .79 is good, between .40 and .59 is fair and less than .40 is poor.⁸⁹ Kappa values are negatively influenced by a lack of variability in observed ratings. Chance agreement calculations increase as variability of observed ratings decrease resulting in deceptively low kappa values.⁸⁹ As the kappa statistic is calculated using only the frequencies along the agreement diagonal, it assumes that all disagreements are of equal seriousness. The grading scale for the DGI consists of four levels. Clinical consequences are greater if scores differ by greater than one level. The kappa statistic was weighted incrementally. The greater the difference in the scores the higher the weight on the kappa statistic.

The Spearman Rank Correlation Coefficient was calculated for DGI total scores between raters and between tests to evaluate for inter-rater and intra-rater reliability. The Spearman Rank Correlation Coefficient is a measure of correlation or relationship between two independent ordinal measures.⁸⁹ Although it does not provide information on the exact agreement of observed ratings, it provides an indication of the relationship between the total scores or systematic error. Scores given by the raters that differ consistently to the same degree will result in lower percent agreement or kappa statistic but higher correlation or Spearman Rho.

Results

Thirty subjects aged 27-88 years (mean=61.17 years) volunteered to participate in the study. The subjects included seven men and twenty-three women. Descriptive information for each subject is included in table 9. DGI individual item and total scores given by the primary investigator for each subject are listed in table 10. The highest score possible was 24. Total scores ranged from 13 to 24. The mode was 21. As there was no more than one level difference between raters or between tests on any individual DGI item, it was not necessary to weight kappa. Although every effort was made to include subjects of varying balance abilities, there was little variability in subject performance of certain items (table 10). This may have yielded deceptively low estimates of reliability. For this reason both kappa and percent agreement were calculated and reported.

The amount of agreement between scores obtained when raters concurrently completed the Dynamic Gait Index was calculated to determine inter-rater reliability. Percent agreement, kappa coefficients and p-values for inter-rater reliability of individual DGI items are listed in table 11. Inter-rater reliability of individual items varied from poor to excellent based on kappa coefficient values ($k = .35-1.00$, $p < .05$ when calculated). The percent agreement of these items ranged from 73% to 97%. Composite kappa values demonstrated good overall inter-rater reliability of total DGI scores ($k = .64$). Spearman rank order correlation coefficient demonstrated excellent correlation between the total DGI scores of both raters ($r = .95$, $p < .0001$). The primary investigator consistently scored the subject's performance higher on items one and two, ambulation at normal and varied speeds (tables 12 and 13), while for items three and four, ambulation

with head turns, she consistently scored the subjects lower than the second rater (tables 14 and 15).

Intra-rater reliability was determined by calculating the amount of agreement between scores obtained during two trials evaluated by the same rater. Percent agreement, kappa coefficient and p-values for intra-rater reliability of individual DGI items are listed in table 16. Intra-rater reliability of individual items varied from fair to excellent based on kappa values ($k = .44-.94$, $p < .05$ when calculated). Percent agreement of these items ranged from 70% to 90%. Composite kappa values demonstrated good overall intra-rater reliability of DGI ($k = .63$). Fair but significant correlation was demonstrated between the repeated total DGI scores using the Spearman rank order correlation coefficient ($r = .80$, $p < .0001$). Fourteen subjects demonstrated the same score on the re-test as the original test, 14 demonstrated increased scores and two demonstrated lower scores (table 17).

Kappa coefficient values may be deceptively low especially with limited variability of data. Item six, ambulation around obstacles, demonstrated poor inter-rater reliability ($k = .35$) even though percent agreement was 80%. There was little variability in subject's performance on this item, with subjects scoring mostly twos and threes (table 18). Items three and four, ambulation with head turns, demonstrated the greatest variability, subjects scored from zero to three (tables 14 and 15). These items demonstrated fair reliability ($k = .57, .58$) despite a 73 percent agreement. These two items also were the most difficult for the raters to agree on grading criteria based on the definitions provided.

Discussion

The mean age of the 30 subjects included in the study was 61.7 years, with a range of 27-88 years. Eighteen subjects were diagnosed with unilateral vestibular hypofunction, five subjects diagnosed with cervical vertigo, three with visual dependence, three with central vertigo and one with bilateral vestibular hypofunction. More female subjects participated in the study than males. This is representative of the gender distribution seen in the clinic. The total DGI scores ranged from 13 to 24 out of a possible 24. The median and the mode were 21. Shumway-Cook et al⁸² defined a score of less than 19 out of 24 was indicative of increased risk of falling. The majority of our subjects demonstrated total scores greater than this indicating minimal impairment in the functional balance tasks assessed.

Shumway-Cook et al⁸⁵ investigated reliability of DGI scores during a pilot study using a sample of five community dwelling older adults with varying balance abilities. The subjects included three females and two males with a mean age of 75 years. Five physical therapists trained in the administration of the DGI concurrently scored the subjects on the DGI to determine inter-rater reliability. They reported inter-rater reliability of total DGI scores as .96 when calculated as the ratio of subject variability to total variability.⁸⁶ Inter-rater reliability of the DGI achieved in this study using subjects with vestibular disorders was calculated to be .64 using the composite kappa statistic and .95 using the Spearman rank order correlation coefficient.

Shumway-Cook et al⁸⁵ examined test-retest reliability by having two of the subjects repeat the test one week later. They did not indicate which raters completed the second test. They reported test-retest reliability of total DGI scores of .98 when

calculated as the ratio of subjects variability to total variability.⁸⁶ Intra-rater reliability of total DGI scores achieved in this study using subjects with vestibular disorders was .63 using the composite kappa statistic and .80 using the Spearman rank order correlation coefficient.

It is difficult to compare these outcomes as the statistics used to calculate reliability measure different aspects of reliability. Shumway-Cook et al chose a measure that compared the variability contributed by the raters to the total variability. The smaller the proportion of variability contributed by the raters the closer to one the reliability score would be. They found excellent reliability using this measure. The kappa statistic is a measure of agreement that has been corrected for agreement that occurs by chance. Scores with limited variability lead to deceptively lower kappa values. We found only fair reliability using the kappa statistic. Spearman rank correlation coefficient measures the relationship between the total scores of different raters or tests. Perfect agreement is not necessary. If one rater consistently rated performance an equal amount different from another rater the correlation would be high. This is an acceptable estimate for a clinical tool used by the same therapist to document outcomes. However, if multiple therapists use the tool to measure outcome in the same patient it is more important to document agreement. We found statistically significant correlation between total scores both for between raters and between tests using Spearman rank order correlation coefficient.

Shumway-Cook et al^{85,86} interpreted their reliability scores as excellent for the DGI. There may be several reasons why lower reliability was found in this study with subjects with vestibular disorders. First, the raters in the previous study were trained by the developer of the scale. Rules for deciding categorization of subjects and definitions

of normal behavior may have been provided to raters but not published with the grading criteria. These definitions and the developers input in learning to interpret grading criteria and subject behavior would have improved reliability.

Second, only five subjects were included in the original study while 30 subjects were included in the current study. Shumway-Cook et al⁸⁵ describe their subjects only by age and that they displayed varying balance abilities. They do not provide descriptions of their performance. Increased reliability will be seen with subjects scoring at the extremes of the grading scale. It is generally easier to determine normal and severely abnormal performance. The more difficult subjects to classify are those who score in the intermediate levels. If Shumway-Cook et al⁸⁵ included subjects at the extremes then their calculated reliability would probably be higher. Although the vestibular subjects included in this study were minimally impaired and scored primarily at the upper end of the scale, they scored in the middle ranges on several test items. This could have lowered the calculated reliability.

Third, the community dwelling older adults included in Shumway-Cook et al's⁸⁵ study may have had long standing balance problems that may not have shown change in performance during the week interval between test. Most older adults with balance problems have gradually deteriorating balance function; change in either direction is slow. It would be expected that limited change, if any, would be seen between testing. The subjects with vestibular dysfunction demonstrated symptoms that were more acute. Due to this acute process even minimal intervention and the one hour interval between tests may have contributed to a change in subject performance leading to lower test-retest reliability.

The measurement of reliability is the measure of the three potential sources of error discussed previously in the reliability section: the subject or variable of interest, the rater and the instrument. Each of these sources may have contributed to the low kappa values calculated for this study.

The current study included only 30 subjects. The kappa statistic becomes more useful with greater number of subjects with greater variability. Although data collection was performed during the first or second treatment session to obtain the greatest amount of variability possible, the variability was not as great as anticipated. Several subjects demonstrated significant improvements in their complaints of dizziness and the balance function between the first and second treatments. Kappa calculations may have been greater if all the data collection had been completed during the diagnostic testing or the first treatment session. This was not always feasible due to availability of the raters and time constraints in the clinic. Increasing the number of subjects included in the study or increasing the variability of balance abilities may yield kappa values indicating higher estimates of reliability.

Surprisingly, intra-rater reliability was lower for total scores than was inter-rater reliability. We found a composite kappa of .63 and Spearman rank order correlation coefficient of .80. Both of these values indicate only fair reliability, although the Spearman coefficient was significant. Inter-rater reliability was based on concurrent scoring of the same performance while intra-rater reliability was based on scoring of two separate performances. The subjects actual performance may have differed between these two tests. The subjects were re-tested approximately one hour after the original test. Fourteen subjects demonstrated the same score on the re-test as the original test, 14

demonstrated increased scores and two demonstrated lower scores (table 16). Scores generally differed by no more than two to three points. This difference in scores may be due to a learning effect in performance of the test or actual change in function during the waiting period. Could the minimal intervention the subjects received have improved their balance function? It is known that increasing activity allows for central compensation following vestibular insult. Many patients will restrict their activity prior to intervention because they are afraid of falling or increasing vertigo. Perhaps just the small amount of activity requested during the session improved their confidence in performing the activities. Changes could have also been seen in the subjects attitude toward function because of the explanations of the mechanism and prognosis of their problem provided by the physical therapist. It would be useful to repeat this study with having the subjects receive no intervention or contact with the therapist between testing.

Both raters involved in this study are experienced in the evaluation and treatment of vestibular disorders. The scores given by the raters varied no more than one level on any individual item. This indicates that although there was not perfect agreement there were not gross differences in the interpretation of performance. The items with the lowest percent agreement had the most vague grading criteria, making it difficult to distinguish between one level of performance and another. For example, in items 3 and 4 subjects ambulate with head turns. Raters are asked to judge whether subjects display minor, moderate or severe gait disturbances. These adjectives are briefly described but lack objective criteria. Difficulty was seen in not only determining the degree of abnormality but also whether the gait performance was normal.

Trends were seen in the direction of scoring between the two raters. For items one and two (tables 12 and 13), ambulation at various speeds, the primary investigator consistently scored the subjects performance higher than the second rater while for items three and four (tables 14 and 15) she scored the subjects consistently lower. This may be a result of the positioning of the raters during the test performance. The primary investigator provided all verbal instructions and guarding of the subjects. This placed her lateral and slightly behind the subjects while the other rater stood several feet behind the subjects. From their vantage points the therapists may have seen different gait deviations.

The definition provided in the grading criteria of normal might also not have been sufficient. In item one normal is defined as “walks 20 feet, no assistive device, good speed, no evidence for imbalance, normal gait pattern.”⁸² This requires a judgement by the rater as to what constitutes normal. This may be based on the therapists experience, the age or activity level of the subject. It has been repeatedly documented through research that older adults demonstrate slower gait velocities and increased gait deviations than younger adults.⁹¹⁻⁹⁴ The level of experience of the therapist as to what constitutes normal at varying stages of the lifespan will determine their interpretation of this item.

The primary investigator consistently scored subjects performance lower for items three and four. The second rater never issued a score of zero for any of the subjects. This may have resulted again from the viewing position of the rater, the interpretation of grading criteria or the unwillingness to assign the lowest category. Although both therapists use the scale frequently in clinical practice the majority of patients seen do not demonstrate severe gait deviations therefore criteria for the lower scores are less familiar. The therapist could group together abnormal performance into a familiar category. Items

three and four require interpretation of the amount of sway a subject exhibits as being mild, moderate or severe. The authors briefly discussed their interpretation of these grading criteria prior to beginning the study however the current definitions are open to wide interpretations. It appears that the first rater used a more stringent interpretation of these criteria.

For intra-rater reliability, only a one-hour interval was provided between tests. This was implemented to minimize the change in balance function that might occur in subjects with acute balance disorders over time. Subjects were also receiving treatment at the time of testing. The re-test needed to be completed before the treatment could effect performance. Because of this short interval, the rater may have been biased towards giving the same scores as she remembered giving the first time. This memory of the first score may have led to higher intra-rater reliability. To minimize the effects of this different scoring forms were used for each trial. The primary investigator recognized the possibility of this bias and attempted to control for this. Although the memory of the first test could not be completely erased from the raters memory, during the interval between the tests the rater was involved in patient care activities. The rater did not review the test scores after the first test or transcribe them onto the data sheet until after the second test.

Modifications to the Dynamic Gait Index may improve the reliability and applicability to patients with vestibular disorders. More objective grading criteria would improve reliability of individual items and total DGI score. A Modified DGI is suggested in table 19. This modified Dynamic gait index is provided as an example and has not yet been evaluated clinically. Instruction on administration, and grading of the test as well as recommended training scenarios could also add to its reliability.

Item one, ambulation at self paced speed, demonstrated good inter-rater but only fair intra-rater reliability. The reliability may be improved by defining the grading criteria in terms of the amount of deviation from a straight line acceptable for each grading criterion and by defining acceptable ranges of gait speed based on age. Ambulation speeds are suggested based on research performed on men and women of various ages.^{92,95} The speeds used for the normal grading criteria are one standard deviation below the mean ambulation scores for elderly men and women found by Hageman and Blanke.^{92,95} The speeds for mildly impaired scores are between one and two standard deviations below the mean ambulation scores. The speed for scores graded as moderately impaired are two standard deviations below the mean ambulation scores and below. For ease of use in the clinic ambulation speeds are translated into the amount of time in seconds that it would take to ambulate 20 feet. Krebs et al⁷⁷ evaluated ambulation speeds of subjects with bilateral vestibular disorders before and after vestibular rehabilitation. Based on the mean ambulation scores of their subjects it appears that this item would be sensitive in detecting gait speed abnormalities in vestibular dysfunction and would demonstrate improvements seen with vestibular rehabilitation.

Item two, ambulation with changes in gait speed, demonstrated fair inter- and intra-rater reliability. The difficulty in this item was determining between the normal and mild impairment scores. The reliability would be improved by defining the amount of difference in gait speeds that would be significant and further defining the amount of deviation from a straight path, similar to item one. Leiper and Craik⁹⁴ report mean gait velocity when elderly and young women were asked to walk at slow to fast paced gait. It

would be difficult to time the various gait speeds in this item because subjects walk at three different speeds during the 20 feet walk. It is hoped that defining normal ambulation velocities in item one will serve as a reference point for clinicians scoring this item.

Item three, ambulation with horizontal head turns, demonstrated fair inter-rater reliability but good intra-rater reliability. The major difference in determining the grade for this item was determining the amount of sway that is normal and the amount of sway that constitutes mild, moderate or severe impairment. Again, the amount of sway was more objectively defined to improve reliability. The performance of this item was also changed from turning the head to one side and walking for five feet and then turning the head to the other direction and walking for five feet to turning the head from side to side every three steps. It was felt that this more closely duplicates the use of head turns during functional ambulation tasks.

Fair inter- and intra-rater reliability was demonstrated for item four, ambulation with vertical head turns. As on item three the greatest difficulty in categorizing subjects was determining the amount of sway that was normal and the amount that was indicative of mild, moderate and severe impairment. The grading criteria was again more objectively defined by providing sway limits for each grading criteria. To improve functional correlation the instructions for performance were also changed so that the head was moved up and down every three steps instead of moving the head only once every five feet.

Gait with pivot turn, item five, was demonstrated to have fair inter-rater reliability and excellent intra-rater reliability. Difficulty grading this item resulted from a lack of

exhaustive criteria. To obtain a normal score a subject must pivot safely within three seconds and stop quickly with no loss of balance. Mild impairment is defined as turning safely in greater than three seconds and stopping with no loss of balance. None of the grading levels include the subject who turns in less than three seconds and stops with mild loss of balance or requiring several small steps to regain balance. Grading criteria addressing this was added to level two to make the grading criteria exhaustive and improve reliability.

Item six, step over obstacle, demonstrated poor inter-rater reliability and fair intra-rater reliability. Despite the lower reliability demonstrated, this item reflects an important function for subjects with vestibular disorders. The difficulty in obtaining reliability on this item appears to be in the definition of normal gait velocity and/or how much slowing down is normal before stepping over an obstacle. Adding the normal gait velocities listed in item one would improve objectivity of this item. The velocity criteria listed in table 19 were calculated from the normal velocity scores given in item one and adding one second to account for the time it takes to step over the box.

Excellent inter-rater reliability and good intra-rater reliability were demonstrated on item seven, ambulation around obstacles. Although this item demonstrated high reliability, it did not distinguish between subjects. Twenty-seven of the subjects received a score of normal or three on this item. The remaining three subjects received a two or mildly impaired score on this item. Replacing this item with items evaluating ambulation with a narrow base of support and with ambulation with the eyes closed may improve the sensitivity in detecting postural instability in patients with vestibular disorders.

Inter-rater and intra-rater reliability for item eight, ambulation on stairs was excellent. Perfect agreement was obtained between both raters on this item. Performance on this item varied from subjects scoring normal to moderately impaired. This item also demonstrated the greatest stability between one test to the next. No changes in administration or grading criteria of this item are required although further research would be helpful to determine if this item would be sensitive to changes seen with rehabilitation.

Conclusions

The Dynamic Gait Index demonstrated only fair reliability when used with subjects with vestibular disorders. Use of the Dynamic Gait Index in this population should be used with caution at this time due to the lack of strong reliability. Without sufficient reliability the clinical significance of changes in scores of this functional gait assessment is unclear. Future research is needed in modifying the Dynamic Gait Index to improve reliability, conduct sensitivity and specificity determination, and correlate with other tests of postural stability and disability measures.

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TABLES

Table 1 – Fregly and Graybiel Ataxia Test Battery.⁴⁶⁻⁴⁹

Fregly and Graybiel Ataxia Test Battery	
All tests are performed wearing shoes on a hard floor without rugs.	
1.	Sharpened Romberg: Standing in tandem heel to toe position with eyes closed, arms folded against chest and body erect for a maximum of 60 seconds.
2.	Walk eyes open: Walking heel to toe with feet in tandem position and arms folded against chest while in a body erect position on ¼" wide by 8' long rail, five steps per trial. (1973, only) ⁴⁶
3.	Stand eyes open: Standing heel to toe in a tandem position and arms folded against the chest while in a body erect position on a ¼" wide rail for a maximum of 60 seconds.
4.	Stand eyes closed: Standing heel to toe in a tandem position and arms folded against the chest while in a body position on a 2 ¼" wide by 30" long rail for a period of 60 seconds.
5.	Stand one leg eyes closed: Standing stationary on the floor on each leg for 30 seconds while arms are folded against the chest and body in erect position.
6.	Walk on floor eyes closed (WOFEC): Walking on the floor eyes closed with arms folded against the chest, body erect and feet aligned heel to toe in tandem for a distance of 12'. The number of steps taken in a straight line are counted for a maximum of 10 steps each for three trials.
7.	Walk a line eyes closed (WALEC): Walking on the floor eyes closed with arms folded against the chest, body erect and feet aligned heel to toe in tandem for a distance of 12'. The distance deviated from the line is measured only for trials in which the subject does not violate the foot position. (1968 only) ⁴⁸

Table 2 – Berg Balance Test Subtests.⁵⁸

Item	Description
1.	Sitting to standing
2.	Standing unsupported
3.	Sitting unsupported
4.	Standing to sitting
5.	Transfers
6.	Standing with eyes closed
7.	Standing with feet together
8.	Reaching forward with an outstretched arm
9.	Retrieving object from floor
10.	Turning to look behind
11.	Turning 360°
12.	Placing alternate foot on stool
13.	Standing with one foot in front of the other foot
14.	Standing on one foot

Each task is scored on an ordinal scale from 0-4, 4 = movement performed independently, all time frames given are achieved. 0 = subject is unable to perform the movement. Maximum score =56

Table 3 – Performance Oriented Mobility Assessment Subtests.⁵⁹

<i>Balance Tests</i>		<i>Gait Tests</i>	
1.	Sitting balance	1.	Initiation of gait
2.	Arises from sitting	2.	Step length and height
3.	Immediate standing balance	3.	Step symmetry
4.	Standing balance	4.	Step continuity
5.	Nudged balance	5.	Gait path
6.	Eyes closed	6.	Trunk position
7.	Turning 360°	7.	Walking Stance
8.	Sitting down		

Table 4 – Clinical Test of Sensory Interaction in Balance.⁶⁹

	Trial 1		Trial 2	
	Time	Sway	Time	Sway
Eyes Open, Firm Surface				
Eyes Closed, Firm Surface				
Visual Dome, Firm surface				
Eyes Open, Foam Surface				
Eyes Closed, Foam Surface				
Visual Dome, Foam Surface				

Time: maximum of 30 seconds. Sway: 1=normal sway, 0=abnormal (symmetric or excessive sway).

Table 5 – Tasks for Observational Gait Analysis.

1.	Ambulate with horizontal and vertical head movements
2.	Walk and stop quickly
3.	Walk and manipulate objects with hands
4.	Negotiate stairs with and without carrying objects
5.	Side stepping
6.	Backward walking
7.	Tandem walking
8.	Marching
9.	Ambulate in figure eight

All tasks are performed with eyes open and eyes closed.²³

Table 6 – Components of the Gait Abnormality Rating Scale (GARS)⁷⁷

- | | |
|-----|---|
| 1. | Variability - a measure of inconsistency and arrhythmicity of stepping and of arm movements. |
| 2. | Guardedness - hesitancy, slowness, diminished propulsion and lack of commitment in stepping and arm swing. |
| 3. | Weaving - an irregular and wavering line of progression. |
| 4. | Waddling - a broad-based gait characterized by excessive truncal crossing of the midline and side bending. |
| 5. | Staggering - sudden and unexpected laterally directed partial losses of balance. |
| 6. | Percent time in Swing - a loss in the percentage of the gait cycle constituted by the swing phase. |
| 7. | Foot Contact - the degree to which heel strikes the ground before the forefoot. |
| 8. | Hip ROM - the degree of loss of hip range of motion seen during the gait scale. |
| 9. | Knee ROM - the degree of loss of knee range of motion seen during the gait scale. |
| 10. | Elbow Extension - a measure of the decrease of elbow range of motion. |
| 11. | Shoulder Extension - a measure of the decrease of shoulder range of motion. |
| 12. | Shoulder Abduction - a measure of pathological increase in shoulder range of motion laterally. |
| 13. | Arm-Heelstrike Synchrony - the extent to which the contralateral movements of arm and leg are out of phase. |
| 14. | Head Held Forward - a measure of the pathological forward projection of the head relative to the trunk. |
| 15. | Shoulders Held Elevated - the degree to which the scapular girdle is held higher than normal. |
| 16. | Upper trunk Flexed Forward - a measure of kyphotic involvement of the trunk. |
| 17. | Total GARS - The sum of the individual component scores. |

Table 7 – Components of the Modified Gait Abnormality Rating Scale.⁷⁴

Variability
Guardedness
Staggering
Foot Contact
Hip Range of Motion
Shoulder Extension
Arm-Heelstrike Synchrony

Table 8 – Dynamic Gait Index⁸²

<p>1. Gait Level Surface. Instructions: <i>Walk at your normal speed from here to the next mark (20').</i> Grading: Mark the highest category which applies.</p> <p>(3) Normal: Walks 20', no assistive devices, good speed, no evidence for imbalance, normal gait pattern.</p> <p>(2) Mild Impairment: Walks 20', uses assistive device, slower speed, mild gait deviations.</p> <p>(1) Moderate Impairment: Walks 20', slow speed, abnormal gait pattern, evidence for imbalance.</p> <p>(0) Severe Impairment: Cannot walk 20' without assistance, severe gait deviations or imbalance.</p>
<p>2. Change in Gait Speed. Instructions: <i>Begin walking at your normal pace (for 5'), when I tell you "go," walk as fast as you can (for 5'). When I tell you "slow," walk as slowly as you can (for 5').</i> Grading: Mark the highest category which applies.</p> <p>(3) Normal: Able to smoothly change walking speed without loss of balance or gait deviation. Shows a significant difference in walking speeds between normal, fast and slow speeds.</p> <p>(2) Mild Impairment: Is able to change speed but demonstrates mild gait deviations, or no gait deviations but unable to achieve a significant change in velocity, or uses an assistive device.</p> <p>(1) Moderate Impairment: Makes only minor adjustments to walking speed, or accomplishes a change in speed with significant gait deviations or changes speed but loses balance but is able to recover and continue walking.</p> <p>(0) Severe Impairment: Cannot change speeds, or loses balance and has to reach for wall or be caught.</p>
<p>3. Gait with Horizontal Head Turns. Instructions: <i>Begin walking at your normal pace. When I tell you to "look right," keep walking straight but turn your head to the right. Keep looking right until I tell you "look left," then keep walking straight but turn your head to the left. Keep your head to the left until I tell you, "look straight," then keep walking straight, but return your head to the center.</i> Grading: Mark the highest category which applies.</p> <p>(3) Normal: Performs head turns smoothly with no change in gait.</p> <p>(2) Mild Impairment: Performs head turns smoothly with slight change in gait velocity, i.e. minor disruption to smooth gait path or uses walking aid.</p> <p>(1) Moderate Impairment: Performs head turns with moderate change in gait velocity, slows down, staggers but recovers, can continue to walk.</p> <p>(0) Severe Impairment: Performs task with severe disruption of gait, i.e. staggers outside 15" path, loses balance, stops, reaches for wall.</p>
<p>4. Gait with Vertical Head Turns. Instructions: <i>Begin walking at your normal pace. When I tell you to "look up," keep walking straight, but tip your head and look up. Keep looking up until I tell you, "look down." Then keep walking straight and turn your head down. Keep looking down until I tell you, "look straight," then keep walking straight, but return your head to the center.</i> Grading: Mark the highest category which applies.</p> <p>(3) Normal: Performs head turns with no change in gait.</p> <p>(2) Mild Impairment: Performs task with slight change in gait velocity i.e., minor disruption to smooth gait path or uses walking aid.</p> <p>(1) Moderate Impairment: Performs task with moderate change in gait velocity, slows down, staggers but recovers, can continue to walk.</p> <p>(0) Severe Impairment: Performs task with severe disruption of gait, i.e., staggers outside 15" path, loses balance, stops, reaches for wall.</p>
<p>5. Gait and Pivot Turn Instructions: <i>Begin with walking at your normal pace. When I tell you, "turn and stop," turn as quickly as you can to face the opposite direction and stop.</i> Grading: Mark the highest category which applies.</p> <p>(3) Normal: Pivot turns safely within 3 seconds and stops quickly with no loss of balance.</p> <p>(2) Mild Impairment: Pivot turns safely in > 3 seconds and stops with no loss of balance.</p> <p>(1) Moderate Impairment: Turns slowly, requires verbal cueing, requires several small steps to catch balance following turn and stop.</p> <p>(0) Severe Impairment: Cannot turn safely, requires assistance turn and stop.</p>

Table 8 – Dynamic Gait Index⁸² (cont.)

<p><u> </u> 6. Step over Obstacle.</p> <p>Instructions: <i>Begin walking at your normal speed. When you come to the shoe box, step over it, not around it, and keep walking.</i></p> <p>Grading: Mark the highest category which applies.</p> <p>(3) Normal: Is able to step over box without changing gait speed; no evidence for imbalance.</p> <p>(2) Mild Impairment: Is able to step over box, but must slow down and adjust steps to clear box safely.</p> <p>(1) Moderate Impairment: Is able to step over box but must stop, then step over. May require verbal cueing.</p> <p>(0) Severe Impairment: Cannot perform without assistance.</p> <p><u> </u> 7. Step Around Obstacles.</p> <p>Instructions: <i>Begin walking at your normal speed. When you come to the first cone (about 6' away), walk around the right side of it. When you come to the second cone (6' past first cone), walk around it to the left.</i></p> <p>Grading: Mark the highest category which applies.</p> <p>(3) Normal: Is able to walk around cones safely without changing gait speed; no evidence of imbalance.</p> <p>(2) Mild Impairment: Is able to step around both cones, but must slow down and adjust steps to clear cones.</p> <p>(1) Moderate Impairment: Is able to clear cones but must significantly slow speed to accomplish task or requires verbal cueing.</p> <p>(0) Severe Impairment: Unable to clear cones, walks into one or both cones, or requires physical assistance.</p> <p><u> </u> 8. Steps</p> <p>Instruction: <i>Walk up these stairs as you would at home (i.e. using the rail if necessary). At the top turn around and walk down.</i></p> <p>Grading: Mark the highest category which applies.</p> <p>(3) Normal: Alternating feet, no rail.</p> <p>(2) Mild Impairment: Alternating feet, must use rail.</p> <p>(1) Moderate Impairment: Two feet to a stair; must use rail.</p> <p>(0) Severe Impairment: Cannot do safely.</p> <p>Total Score <u> </u> (Score <20/24 indicates increased risk of fall).</p>

Table 9 – Subject Information

Subject Number	Age	Gender	Diagnosis	MMSE	DHI
1	67	Female	Unilateral hypofunction	30	69
2	27	Female	Visual dependence	30	83
3	75	Female	Unilateral hypofunction	28	48
4	51	Female	Unilateral hypofunction	30	*
5	73	Female	Unilateral hypofunction	30	*
6	36	Female	Unilateral hypofunction	30	64
7	71	Female	Cervical vertigo	29	*
8	66	Male	Unilateral hypofunction	29	69
9	65	Female	Unilateral hypofunction	30	56
10	39	Female	Cervical vertigo	30	28
11	31	Female	Unilateral hypofunction	30	67
12	73	Female	Unilateral hypofunction	28	69
13	76	Female	Unilateral hypofunction	30	58
14	78	Male	Unilateral hypofunction	30	*
15	48	Female	Cervical vertigo	30	61
16	78	Female	Central vertigo	29	52
17	37	Female	Visual dependence	30	48
18	78	Male	Unilateral hypofunction	30	74
19	41	Female	Unilateral hypofunction	30	60
20	88	Female	Unilateral hypofunction	30	61
21	80	Male	Unilateral hypofunction	28	71
22	50	Female	Cervical vertigo	30	70
23	74	Female	Central vertigo	30	57
24	59	Female	Visual dependence	30	83
25	69	Male	Bilateral hypofunction	30	49
26	47	Male	Unilateral hypofunction	30	72
27	49	Female	Cervical vertigo	30	72
28	60	Female	Central vertigo	30	34
29	72	Male	Unilateral hypofunction	30	68
30	79	Female	Unilateral hypofunction	30	69

* DHI not completed during vestibular function testing.

Table 10 – Dynamic Gait Index individual and total scores given by primary investigator during trial concurrently scored with second rater.

Subject #	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Total
1	3	3	2	2	3	3	3	2	21
2	3	2	2	2	3	3	3	3	21
3	2	2	1	1	1	2	3	2	14
4	3	3	3	3	3	3	3	2	23
5	3	3	2	2	3	3	3	3	22
6	3	3	3	3	3	3	3	3	24
7	3	3	1	2	3	2	3	2	19
8	3	3	3	3	3	2	3	2	22
9	2	2	1	0	3	1	3	1	13
10	3	3	2	3	3	3	3	2	22
11	2	3	2	3	3	2	3	3	21
12	3	2	1	1	3	3	2	2	17
13	2	3	2	3	3	3	3	2	21
14	3	3	2	2	3	3	3	2	21
15	3	2	2	2	1	2	3	3	18
16	2	3	2	1	3	3	2	2	18
17	3	3	1	0	1	3	3	3	17
18	3	3	2	3	3	3	3	2	22
19	3	3	3	3	3	3	3	2	23
20	3	2	2	2	2	3	3	2	19
21	2	3	2	2	3	3	3	2	20
22	2	3	1	0	3	2	2	2	15
23	3	3	0	3	3	3	3	3	21
24	3	3	3	3	3	3	3	3	24
25	3	3	3	3	3	3	3	3	24
26	3	3	2	2	3	3	3	3	22
27	3	3	2	3	3	3	3	3	23
28	3	2	2	3	3	3	3	2	21
29	3	3	3	3	3	3	3	3	24
30	3	3	3	2	2	3	3	2	21

Table 11 – Inter-rater percent Agreement and Kappa Coefficient values for individual items of DGI.

Gait Item Number	Inter-rater Reliability		
	% Agreement	Kappa Value	Significance
1 self paced gait	90%	.73	*
2 gait at various speeds	80%	.52	*
3 gait with horizontal head turns	73%	.57	*
4 gait with vertical head turns	73%	.58	*
5 pivot turn	90%	.59	p.<.00002
6 step over obstacle	80%	.35	*
7 step around obstacle	97%	.84	p.<.00000
8 stairs	100%	1.00	p.<.00000
composite		.64	

* Kappa values calculated by hand as SPSS will only calculate values with equal numbers of rows and columns. Attempts to calculate p-values using macro program from SPSS yielded different kappa values than those calculated by hand. As it was unclear which formula was used to calculate kappa in the computer program, significance levels were not reported. P-values calculated were less than .05.

Table 12 – Matrix table of frequency counts of scores given on item 1, gait at self preferred speed, by both raters when concurrently scoring DGI.

	Rater 2		
Rater 1	1 Moderate impairment	2 Mild impairment	3 Normal
2 Mild impairment	1	5	1
3 Normal	0	1	22

Table 13 – Matrix table of frequency counts of scores given on item 2, gait at fast and slow speeds, by both raters when concurrently scoring DGI.

	Rater 2		
Rater 1	1 Moderate impairment	2 Mild impairment	3 Normal
2 Mild impairment	1	5	1
3 Normal	0	4	19

Table 14 – Matrix table of frequency counts of scores given on item 3, gait with horizontal head turns, by both raters when concurrently scoring DGI.

	Rater 2		
Rater 1	1 Moderate impairment	2 Mild impairment	3 Normal
0 Severe impairment	1	0	0
1 Moderate impairment	2	4	0
2 Mild impairment	0	12	3
3 Normal	0	0	8

Table 15 – Matrix table of frequency counts of scores given on item 4, gait with vertical head turns, by both raters when concurrently scoring DGI.

	Rater 2		
Rater 1	1 Moderate impairment	2 Mild impairment	3 Normal
0 Severe impairment	3	0	0
1 Moderate impairment	2	1	0
2 Mild impairment	0	7	3
3 Normal	0	1	13

Table 16 – Intra-rater percent agreement and Kappa Coefficient values for individual items of DGI

Gait Item Number	Intra-rater Reliability		
	% Agreement	Kappa Value	Significance
1 self paced gait	83%	.51	p. <.00502
2 gait at various speeds	80%	.44	p. <.01572
3 gait with horizontal head turns	77%	.62	*
4 gait with vertical head turns	70%	.52	p.<.00003
5 pivot turn	97%	.87	p.<.00000
6 step over obstacle	83%	.53	p.<.00093
7 step around obstacle	93%	.63	p.<.00056
8 stairs	97%	.94	p.<.00000
composite		.63	

* Kappa values calculated by hand as SPSS will only calculate values with equal numbers of rows and columns. Attempts to calculate p-values using macro program from SPSS yielded different kappa values than those calculated by hand. As it was unclear which formula was used to calculate kappa in the computer program, significance levels were not reported. P-values calculated were less than .05.

Table 17 – DGI scores given by primary investigator on two separate performances of DGI

Subject number	1 st test	2 nd test
1	21	21
2	21	22
3	14	15
4	22	23
5	22	22
6	24	24
7	19	20
8	22	22
9	13	13
10	18	22
11	21	23
12	17	17
13	21	22
14	23	21
15	18	21
16	18	20
17	17	18
18	21	22
19	23	23
20	19	22
21	20	20
22	18	15
23	21	23
24	24	24
25	23	23
26	21	21
27	24	24
28	22	22
29	24	24
30	21	22

Table 18 – Matrix table of frequency counts of scores given on item 6, step over obstacle, by both raters when concurrently scoring DGI.

	Rater 2	
Rater 1	2 Mild Impairment	3 Normal
1 Moderate Impairment	1	0
2 Mild Impairment	2	4
3 Normal	1	22

Table 19 – Modified Dynamic Gait Index

<p>1. Gait Level Surface. Instructions: <i>Walk at your normal speed from here to the next mark (20').</i> Grading: Mark the highest category that applies.</p> <p>(3) Normal: Walks 20' in less than 5.5 seconds, no assistive devices, good speed, no evidence for imbalance, normal gait pattern, deviates no more than 6" from straight path.</p> <p>(2) Mild Impairment: Walks 20' in less than 7 seconds but greater than 5.5 seconds, uses assistive device, slower speed, mild gait deviations, or deviates 6-10" from straight path.</p> <p>(1) Moderate Impairment: Walks 20', slow speed, abnormal gait pattern, evidence for imbalance, or deviates 10-15" from straight path. Requires more than 7 seconds to ambulate 20'.</p> <p>(0) Severe Impairment: Cannot walk 20' without assistance, severe gait deviations or imbalance, deviates greater than 15" from straight path.</p> <p>2. Change in Gait Speed. Instructions: <i>Begin walking at your normal pace (for 5'), when I tell you "go," walk as fast as you can (for 5'). When I tell you "slow," walk as slowly as you can (for 5').</i> Grading: Mark the highest category that applies.</p> <p>(3) Normal: Able to smoothly change walking speed without loss of balance or gait deviation. Shows a significant difference in walking speeds between normal, fast and slow speeds. Deviates no more than 6" from straight path.</p> <p>(2) Mild Impairment: Is able to change speed but demonstrates mild gait deviations, deviates 6-10" from straight path or no gait deviations but unable to achieve a significant change in velocity, or uses an assistive device.</p> <p>(1) Moderate Impairment: Makes only minor adjustments to walking speed, or accomplishes a change in speed with significant gait deviations deviates 10-15" from straight path or changes speed but loses balance but is able to recover and continue walking.</p> <p>(0) Severe Impairment: Cannot change speeds, deviates greater than 15" from straight path or loses balance and has to reach for wall or be caught.</p> <p>3. Gait with Horizontal Head Turns. Instructions: <i>Begin walking at your normal pace. Keep walking straight, approximately every three steps turn your head from side to side, to the right and to the left.</i> Grading: Mark the highest category that applies.</p> <p>(3) Normal: Performs head turns smoothly with no change in gait. Deviates no more than 6" outside straight path.</p> <p>(2) Mild Impairment: Performs head turns smoothly with slight change in gait velocity, i.e. minor disruption to smooth gait path deviates 6-10" outside straight path or uses walking aid.</p> <p>(1) Moderate Impairment: Performs head turns with moderate change in gait velocity, slows down, deviates 10-15" outside straight path but recovers, can continue to walk.</p> <p>(0) Severe Impairment: Performs task with severe disruption of gait, i.e. staggers outside 15" path, loses balance, stops, or reaches for wall.</p> <p>4. Gait with Vertical Head Turns. Instructions: <i>Begin walking at your normal pace. Keep walking straight, approximately every three steps tip your head up and down.</i> Grading: Mark the highest category which applies.</p> <p>(3) Normal: Performs head turns with no change in gait. Deviates no more than 6" outside straight path.</p> <p>(2) Mild Impairment: Performs task with slight change in gait velocity i.e., minor disruption to smooth gait path deviates 6-10" outside straight path or uses walking aid.</p> <p>(1) Moderate Impairment: Performs task with moderate change in gait velocity, slows down, deviates 10-15" outside straight path but recovers, can continue to walk.</p> <p>(0) Severe Impairment: Performs task with severe disruption of gait, i.e., staggers outside 15" path, loses balance, stops, reaches for wall.</p>
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Table 19 – Modified Dynamic Gait Index (cont.)

<p>5. Gait and Pivot Turn Instructions: <i>Begin with walking at your normal pace. When I tell you, "turn and stop," turn as quickly as you can to face the opposite direction and stop.</i> Grading: Mark the highest category which applies. (3) Normal: Pivot turns safely within 3 seconds and stops quickly with no loss of balance. (2) Mild Impairment: Pivot turns safely in > 3 seconds and stops with no loss of balance or pivot turns safely within 3 seconds and stops with mild imbalance, requires small steps to catch balance.. (1) Moderate Impairment: Turns slowly, requires verbal cueing, requires several small steps to catch balance following turn and stop. (0) Severe Impairment: Cannot turn safely, requires assistance to turn and stop.</p> <p>6. Step over Obstacle. Instructions: <i>Begin walking at your normal speed. When you come to the shoe box, step over it, not around it, and keep walking.</i> Grading: Mark the highest category which applies. (3) Normal: Is able to step over box without changing gait speed; no evidence for imbalance. Completes task in less than 6.5 seconds. (2) Mild Impairment: Is able to step over box, but must slow down and adjust steps to clear box safely. Completes task in less than 8 seconds. (1) Moderate Impairment: Is able to step over box but must stop, then step over. May require verbal cueing. Completes task in greater than or equal to 8 seconds. (0) Severe Impairment: Cannot perform without assistance.</p> <p>7. Gait with Narrow Base of Support Instructions: <i>Walk on the floor with arms folded across the chest, feet aligned heel to toe in tandem for a distance of 12'. The number of steps taken in a straight line are counted for a maximum of 10 steps.</i> Grading: Mark the highest category that applies. (3) Normal: Is able to ambulate for 10 steps heel to toe with no staggering, deviates no more than 6" from straight path. (2) Mild Impairment: Ambulates 10 steps heel to toe with no loss of balance, deviates 6-12" from straight path or ambulates only 7-9 steps, deviates no more than 6" from straight path. (1) Moderate Impairment: Ambulates 10 steps heel to toe with greater than 12" deviation or ambulates only 4-7 steps, deviates no more than 6" from straight path. (0) Severe Impairment: Ambulates less than 4 steps heel to toe or cannot perform without assistance.</p> <p>8. Gait with eyes closed Instructions: <i>Walk at your normal speed from here to the next mark (20') with your eyes closed.</i> Grading: Mark the highest category that applies. (3) Normal: Walks 20', no assistive devices, good speed, no evidence for imbalance, normal gait pattern, deviates no more than 6" from straight path. Ambulates 20' in less than 5.5 seconds. (2) Mild Impairment: Walks 20', uses assistive device, slower speed, mild gait deviations, deviates 6-10" from straight path. Ambulates 20' in less than 7 seconds but greater than 5.5 seconds. (1) Moderate Impairment: Walks 20', slow speed, abnormal gait pattern, evidence for imbalance, deviates 10-15" from straight path. Requires more than 7 seconds to ambulate 20'. (0) Severe Impairment: Cannot walk 20' without assistance, severe gait deviations or imbalance, deviates greater than 15" from straight path.</p> <p>9. Steps Instruction: <i>Walk up these stairs as you would at home (i.e. using the rail if necessary). At the top turn around and walk down.</i> Grading: Mark the highest category which applies. (3) Normal: Alternating feet, no rail. (2) Mild Impairment: Alternating feet, must use rail. (1) Moderate Impairment: Two feet to a stair; must use rail. (0) Severe Impairment: Cannot do safely.</p> <p>Total Score _____ (Score <18/24 indicates increased risk of fall).</p>
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Adapted from Shumway-Cook A and Woolacott M. Motor Control: Theory and Practical Applications. Baltimore, MD. Williams and Wilkins. 1995:322-324.

FIGURES

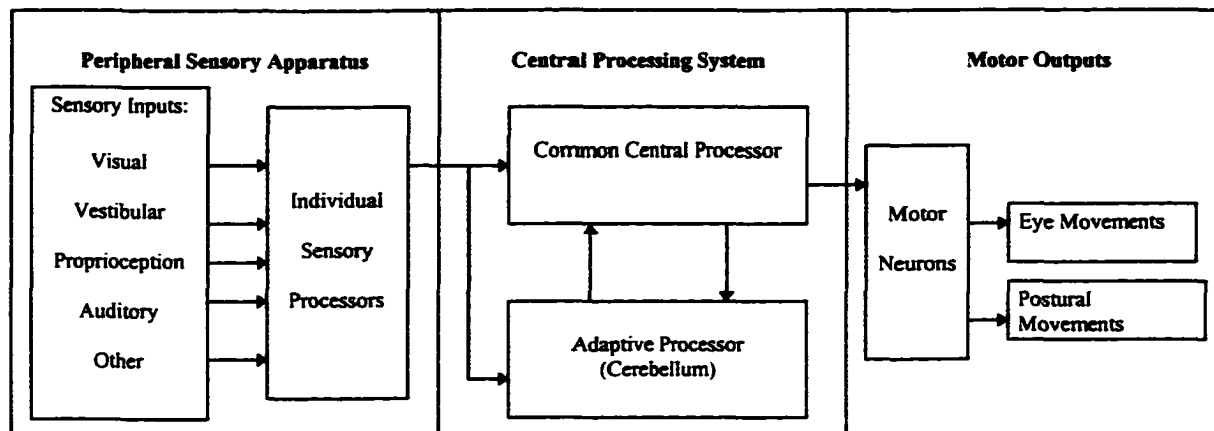


Figure 1. The Organization of the Human Balance System. (Adapted from Hain 1995 and Honrubia 1993.)^{1,2}

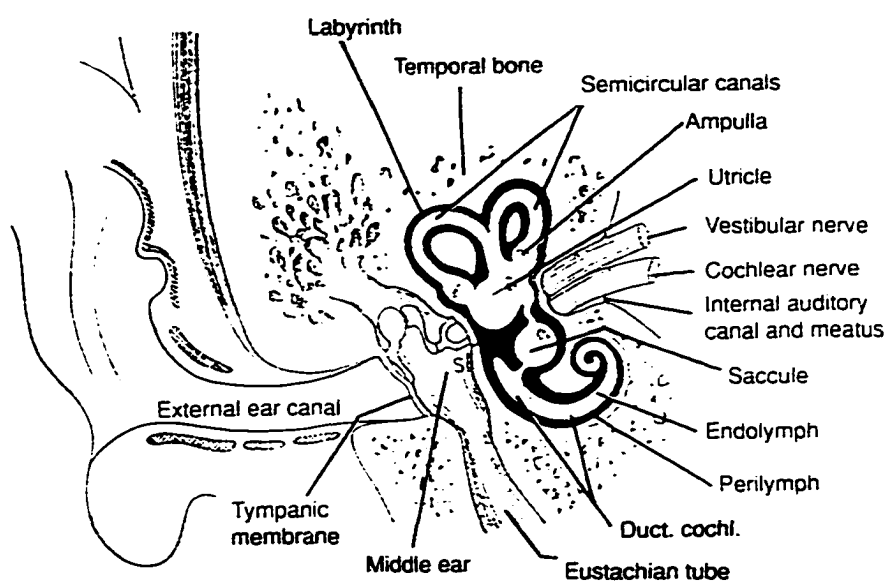


Figure 2 Orientation of peripheral vestibular apparatus within the temporal bone. Reprinted with permission from Hain TC, Hillman MA. Anatomy and physiology of the normal vestibular system. In Herdman SJ. (ed.) *Vestibular Rehabilitation*. FA Davis Co. Philadelphia. 1994:4.

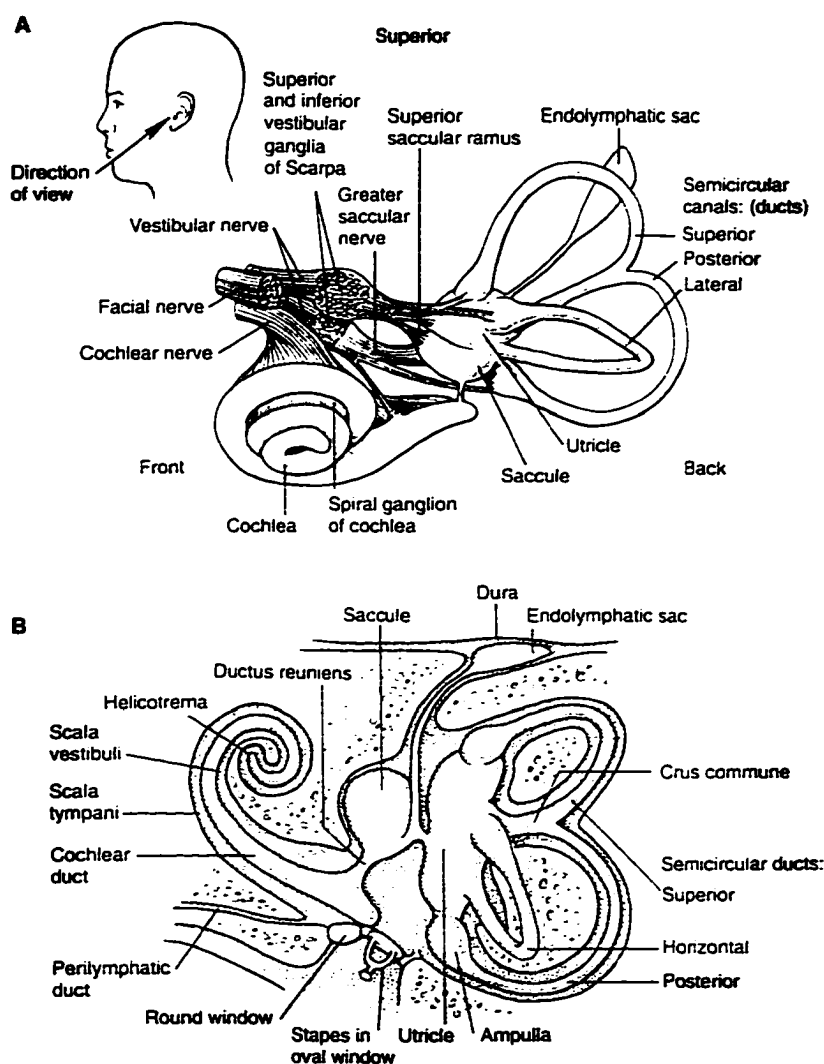


Figure 3

A. Location of vestibular and cochlear divisions of the inner ear with respect to the head.

B. The inner ear is divided into bony and membranous labyrinths. The bony labyrinth is bounded by the petrous portion of the temporal bone. Lying within this structure in the membranous labyrinth, a membrane-bound structure that contains the organs of hearing (the cochlear duct) and equilibrium (the utricle, saccule and semicircular ducts). The space between bone and membrane is filled with perilymph, while the membranous labyrinth is filled with endolymph. Sensory cells in the utricle, saccule and the ampullae of the semicircular ducts respond to motion of the head. (Adapted from Iurato, 1967). Reprinted with permission from Kelly JP. The sense of balance. In Kandel ER, Schwartz JH, Jessell TM. (eds.) *Principles of Neural Science: Third Edition*. Appleton & Lange. Norwalk, Connecticut. 1991:502.

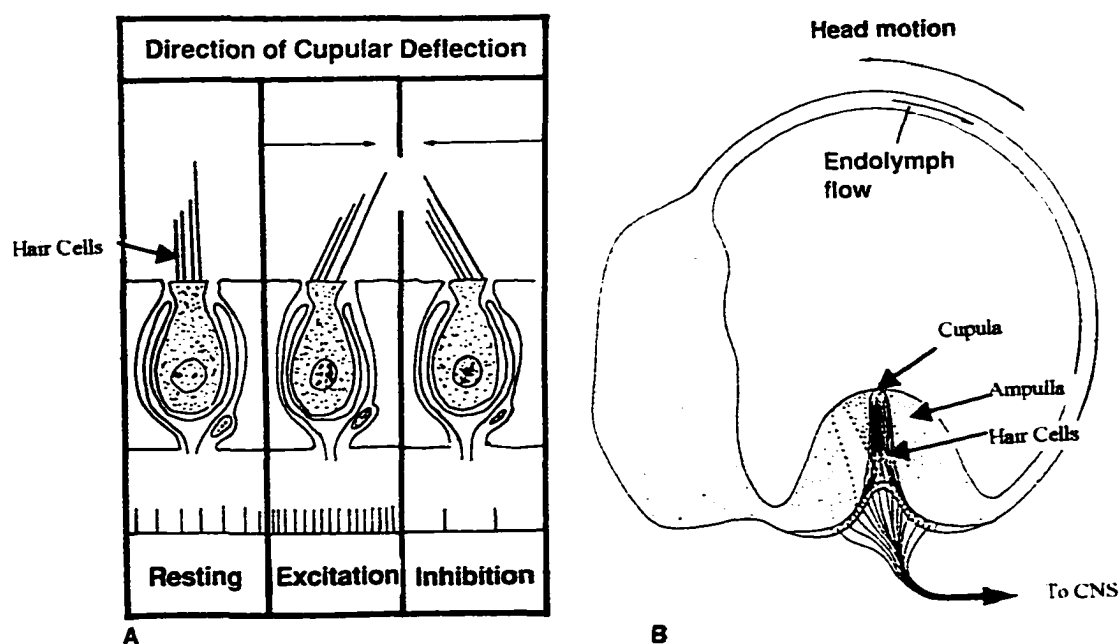


Figure 4 Effects of head rotation on the semicircular canals. **A.** The direction from which hair cells are deflected determines whether hair cell discharge frequency increases or decreases. **B.** Endolymph flow and cupula deflection in response to head motion. Reprinted with permission from Hain TC, Hillman MA. Anatomy and physiology of the normal vestibular system. In Herdman SJ. (ed.) *Vestibular Rehabilitation*. FA Davis Co. Philadelphia. 1994:6

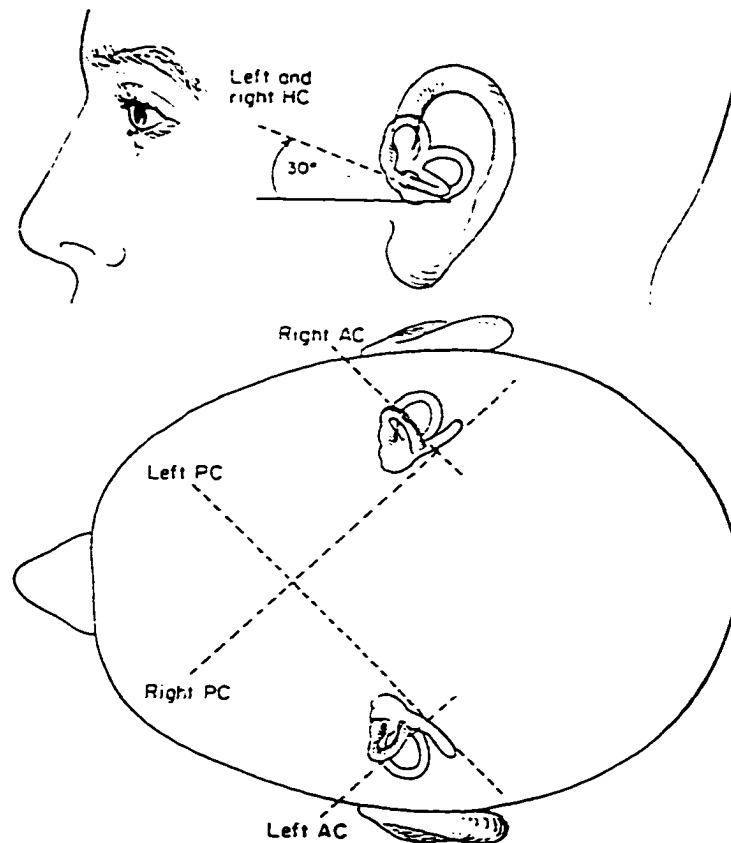


Figure 5 Orientation of the semi-circular canals within the head. HC= horizontal canal, AC= anterior canal, PC= posterior canal. Reprinted with permission from Baloh RW, Honrubia V. *Clinical Neurophysiology of the Vestibular System*. FA Davis Co. Philadelphia. 1990:27.

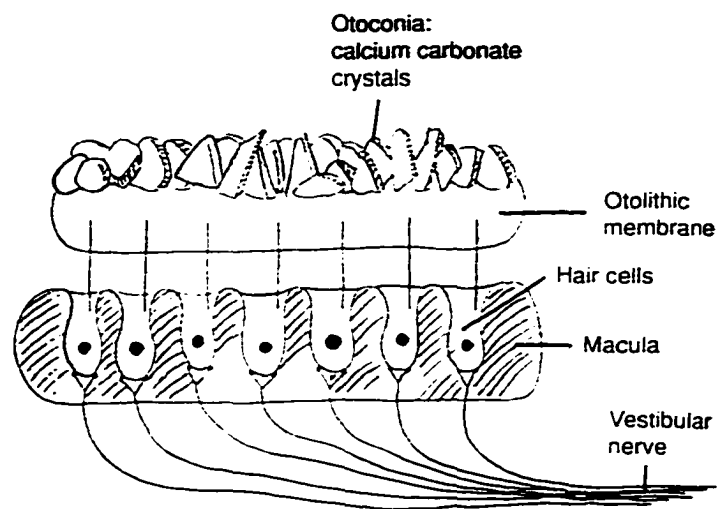


Figure 6 The otolithic macula and its overlying membrane.
Reprinted with permission from Baloh RW, Honrubia V. *Clinical Neurophysiology of the Vestibular System*. FA Davis Co. Philadelphia. 1990:4.

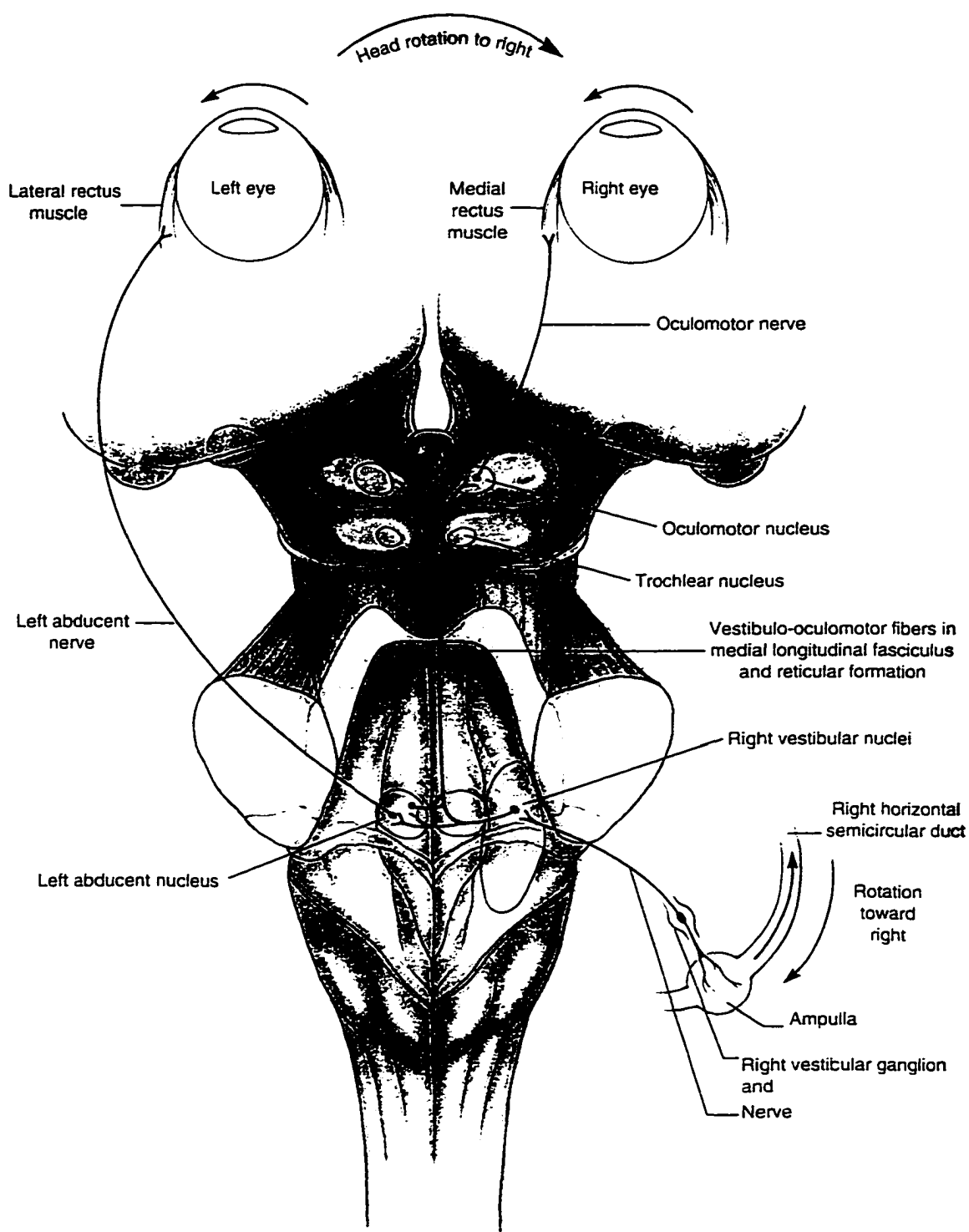


Figure 7 Schematic drawing of dorsal aspect of human brainstem showing vestibulo-ocular reflex on rotations to right. Reprinted with permission from Young PA and Young PH. Basic Clinical Neuroanatomy. Williams and Wilkins. Baltimore, Maryland. 1997:121.

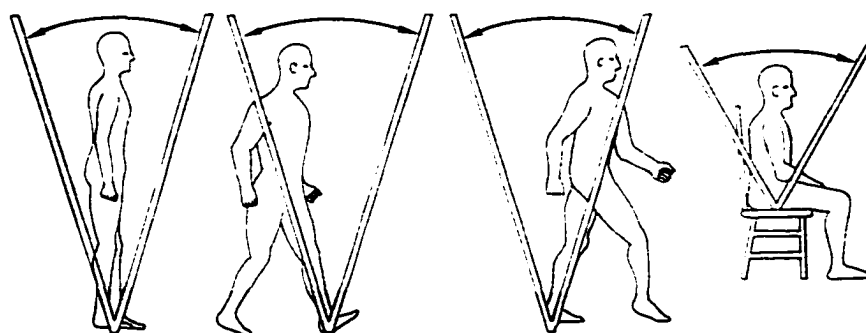


Figure 8 Cones represent range of equilibrium positions within limits of stability for various balance tasks. "Reprinted from Nashner LM. Sensory, neuromuscular and biomechanical contributions to human balance. In Duncan PW. (ed) Balance: Proceedings of APTA Forum. APTA. Alexandria, VA. 1990:6, with permission of the American Physical Therapy Association."

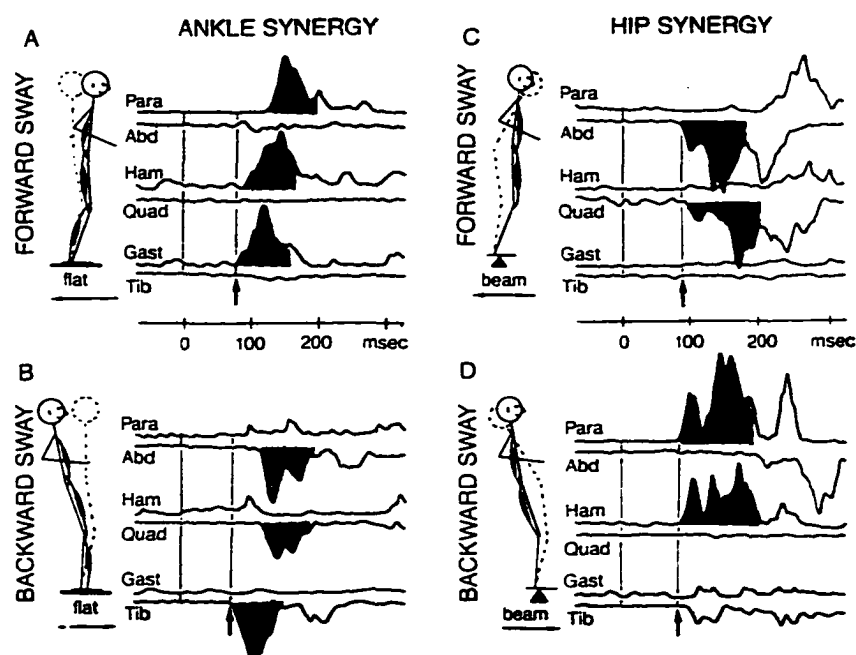


Figure 9 EMG responses associated with ankle and hip movement strategies. Muscles on the figures correspond to those named on the graph. Solid line figures depict position after movement of the support surface; dashed-lines figures depict the target return to equilibrium position. The vertical line to the right (with arrow) shows the time that the muscles begin to contract. "Reprinted from Nashner LM. Sensory, neuromuscular and biomechanical contributions to human balance. In Duncan PW. (ed) Balance: Proceedings of APTA Forum. APTA. Alexandria, VA. 1990:6, with permission of the American Physical Therapy Association."

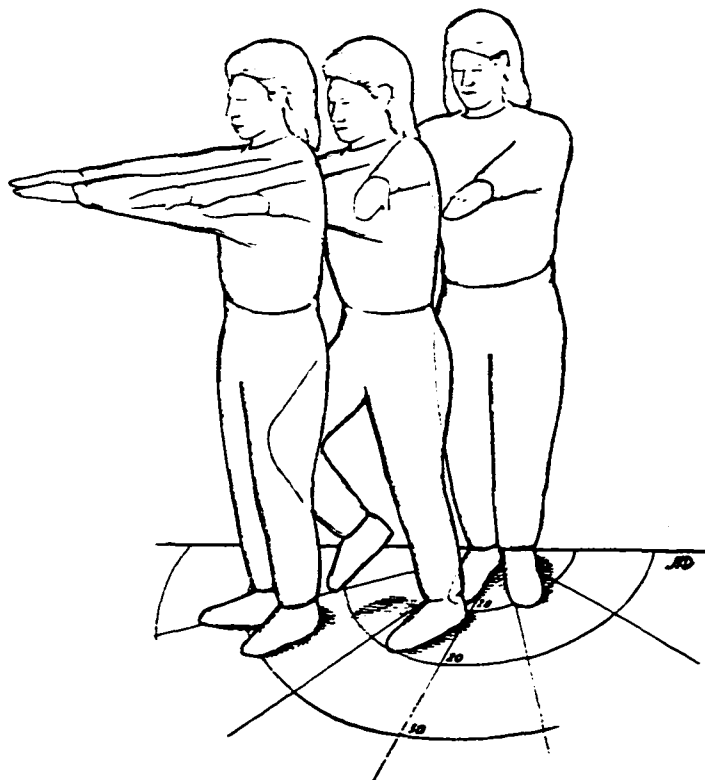


Figure 10. Fukuda stepping test assesses postural stability while the patient marches in place with the eyes open and closed. Forward progression, direction and degree of rotation are measured. Reprinted with permission from Borello-France DF, Whitney SL, Herdman SJ. Assessment of vestibular hypofunction. In Herdman SJ. (ed.) Vestibular Rehabilitation. FA Davis. Philadelphia. 1994:264.

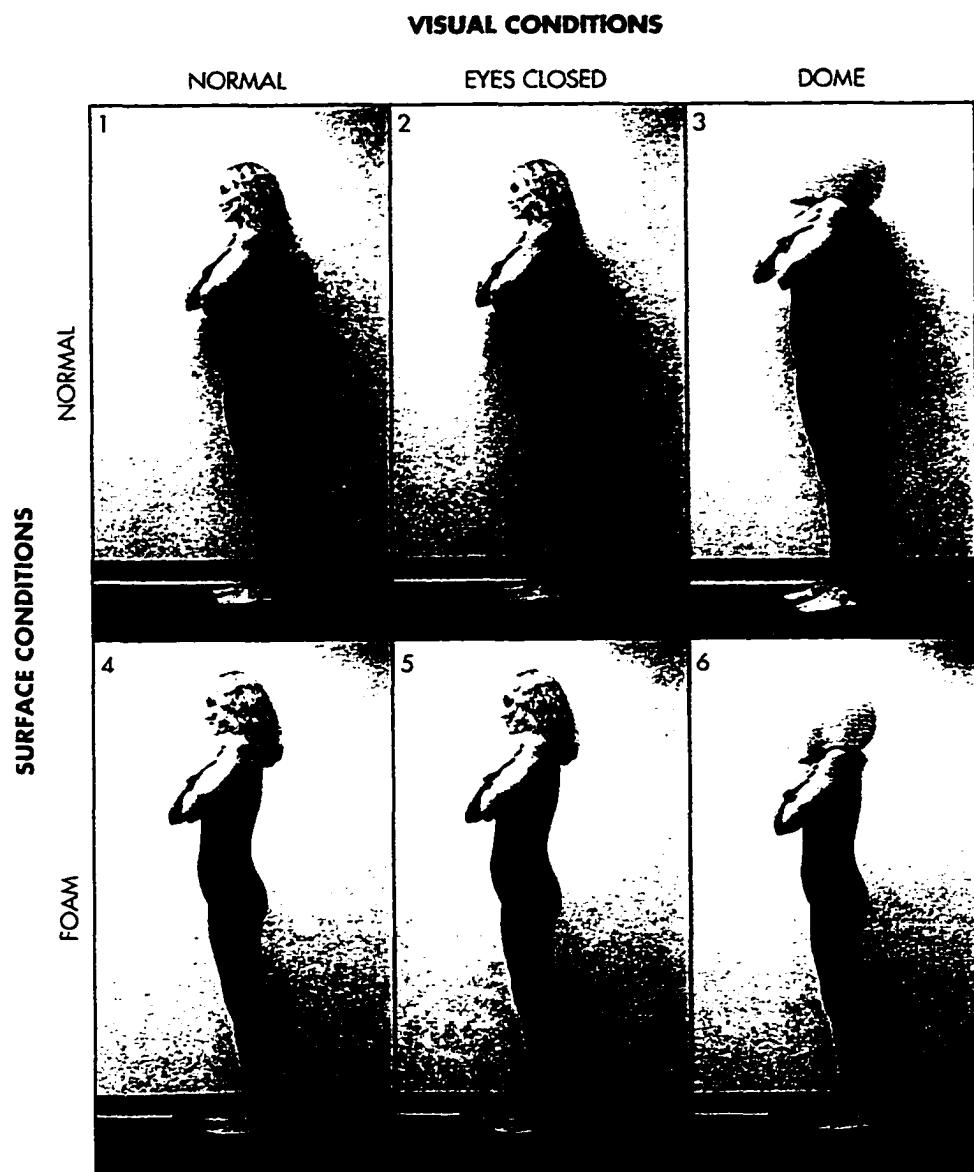


Figure 11 The clinical test of sensory interaction in balance (CTSIB) uses foam and a Japanese lantern to replicate the six sensory conditions. A stop watch is used to time trials. Reprinted with permission from Allison L. Balance disorders. In: Umphred DA. (ed.) Neurological Rehabilitation. Third Edition. Mosby Year Book. St Louis, MO. 1995:817.

APPENDIX A

INFORMED CONSENT DOCUMENT

Old Dominion University
College of Health Sciences
Bon Secours De Paul Medical Center
Department of Physical Therapy

TITLE OF RESEARCH: Reliability of Dynamic Gait Index.

INVESTIGATORS: Diane M. Wrisley, PT, NCS, Marlene Kuntz, PT and Martha L. Walker, MS, PT.

DESCRIPTION OF RESEARCH:

Several studies have investigated the use of the Dynamic Gait Index as a tool for predicting falls in the elderly. The purpose of this study is to examine the reliability of the Dynamic Gait Index with a population of patients with dizziness or inner ear disorders.

You will be participating in a study involving a walking test with eight items including walking with head turns, turning quickly, stepping over and around obstacles and negotiating stairs. You will be asked to complete this test two times with a 45-minute rest between trials.

EXCLUSIONARY CRITERIA:

You have completed the mini mental status evaluation and health questionnaire. To the best of your knowledge, you should not have any cognitive or neuromuscular dysfunction that would prohibit your participation in this study.

RISKS AND BENEFITS:

The testing procedures that you undergo may result in loss of balance or falling. There is a possible risk of falling or loss of balance. There also exists the possibility that you may be subject to risks that have not yet been identified. These risks are minimal and all precautions will be taken to ensure your safety including close guarding as you perform the activities. Information obtained from the Dynamic Gait Index will be used to guide your physical therapy treatment. Pertinent information relative to your responses to this study will be discussed with you by one of the investigators of this study.

ALTERNATIVE TREATMENT:

You have the option of refusing to participate in this test or in vestibular rehabilitation. The skills assessed by this test are vital towards designing your treatment program, although there are other gait assessments available they do not observe all the movements that can be used in planning your treatment. You have the right to request that your gait be assessed in more traditional methods instead of participating in this study.

COSTS AND PAYMENTS:

Your efforts in this study are voluntary, and you will not receive remuneration to help defray incidental expenses associated with participation.

NEW INFORMATION:

Any new information obtained during the course of this research that is directly related to your willingness to continue to participate in this study will be provided to you.

CONFIDENTIALITY:

Any information obtained about you from this research, including questionnaires, medical history, and laboratory findings will be kept confidential by coding the data. Data derived from this study could be used in reports, presentations and publications, but you will not be individually identified. If requested, your records may be subpoenaed by court order or may be inspected by federal regulatory authorities.

WITHDRAWAL PRIVILEGE:

You are free to refuse to participate in this study or to withdraw at any time and your decision to withdraw will not adversely affect your care at this institution or cause a loss of benefits to which you might otherwise be entitled. If you do decide to withdraw, you agree to undergo all trial evaluations necessary for your safety and well being as determined by the investigators. The investigators reserve the right to withdraw your participation at any time throughout this investigation if they observe any contraindication to your continued participation.

COMPENSATION FOR ILLNESS AND INJURY:

In the event of injury or illness resulting from the research protocol, no monetary compensation will be made. Any immediate emergency medical treatment, which may be necessary, will be available to you without charge by the investigators. Financial compensation for a research related injury or illness, lost wages, disability or discomfort is not available. However, your legal rights are not waived by signing this consent form. Old Dominion University provides no compensation plan for free medical care plan to compensate you for such injury. In the event that you believe you have suffered an injury as a result of your participation in any research program, you may contact Diane M. Wrisley at 757-889-5201 or Martha Walker at 757-683-4519. If you have any questions regarding your rights as a human subject you may contact Dr. Val Derlega, Chair of the Old Dominion University Institutional Review Board at 757-683-3118 whom will discuss the matter with you.

VOLUNTARY CONSENT:

I certify that I have read the preceding sections of this document, or it has been read to me; that I understand the contents; and that any questions I have pertaining to the research have been, or will be answered by Diane M. Wrisley, PT, NCS (889-5201). If I have any concerns, I can express them to the Chair of the College of Community Health and Physical Therapy Human Subjects Committee and/or Dr. Val Derlega, Chair of the University Institutional Review Board, Old Dominion University, 683-3118. A copy of this informed consent form has been given to me. My signature below indicates that I have freely agreed to participate in this investigation.

Subject's Signature

Date

Witness's Signature

Date**INVESTIGATOR'S STATEMENT:**

I certify that I have explained to the subject, whose signature appears above, the nature and purpose of the potential benefits and possible risks associated with participation in this study. I have answered any questions that have been raised by the subject and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature on the date stated on this consent form.

Investigator's Signature

Date

APPENDIX B

36

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Dear Sir or Madam:

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1. Hain TC, Hillman MA. Anatomy and physiology of the normal vestibular system. In Herdman SJ. (ed). Vestibular Rehabilitation. FA Davis Co. Philadelphia. 1994; page 2 figure 1-2 and page 6 figure 1-4.
2. Borello-France DF, Whitney SL, Herdman SJ. Assessment of vestibular hypofunction. In Herdman SJ. (ed). Vestibular Rehabilitation. FA Davis Co. Philadelphia. 1994; 264 figure 13-6.
3. Baloh RW, Honrubia V. Clinical Neurophysiology of the Vestibular System. FA Davis Co. Philadelphia. 1990; page 4 figure 1.1 and page 5 figure 1.2.

I appreciate your consideration of this matter. You may send a reply to the address listed above or contact me at 757-930-1372 or dmwrispt@erols.com. Thank you in advance for your assistance.

Sincerely,


Diane M. Wrisley, PT, NCS

October 29, 1998

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1. Shumway-Cook A, Woollacott MH. Motor Control: Theory and Practical Applications. Williams and Wilkins. Baltimore, Maryland. 1995;215, figure 10.8.
2. Young PA, Young PH. Basic Clinical Neuroanatomy. Williams and Wilkins. Baltimore, Maryland. 1997;121, figure 10.4.

I appreciate your consideration of this matter. You may send a reply to the address listed above or contact me at 757-930-1372 or dmwrispt@erols.com. Thank you in advance for your assistance.

Sincerely,

Diane M. Wrisley
Diane M. Wrisley, PT, NCS

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Nashner LM. Sensory, neuromuscular and biomechanical contributions to human balance. In: Duncan PW. (ed.) Balance: Proceedings of APTA Forum. APTA. Alexandria, VA. 1990: page 6 figure 1 and page 9 figure 7.

I appreciate your consideration of this matter. You may send a reply to the address listed above or contact me at 757-930-1372 or dmwrispt@erols.com. Thank you in advance for your assistance.

Sincerely,

Diane M. Wrisley

Diane M. Wrisley, PT, NCS

APTA, 1111 North Fairfax St, Alexandria, VA 22314-1488

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Allison L. Balance disorders. In: Umphred DA. (ed.) *Neurological Rehabilitation. Third Edition.* Mosby Year Book. St Louis, MO. 1995: page 817 figure 28-11.

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Diane M. Wrisley
Diane M. Wrisley, PT, NCS

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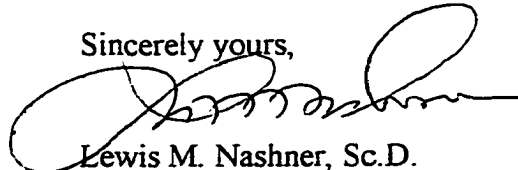
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I wish you the best of success on your thesis project.

Sincerely yours,



Lewis M. Nashner, Sc.D.
President

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CLACKAMAS, OR 97015-9611
USA ONLY 800-767-6744
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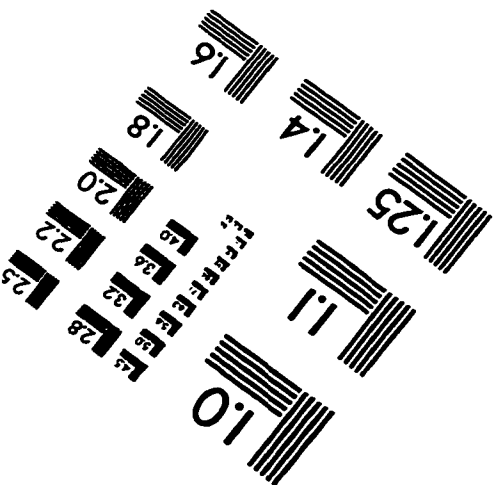
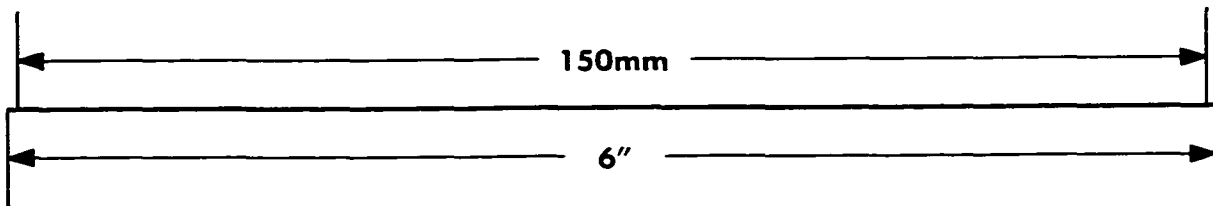
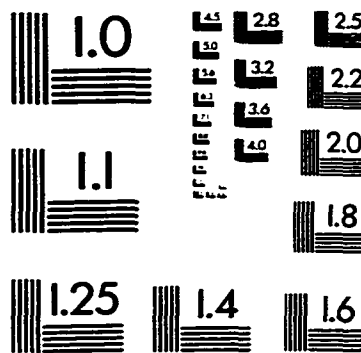
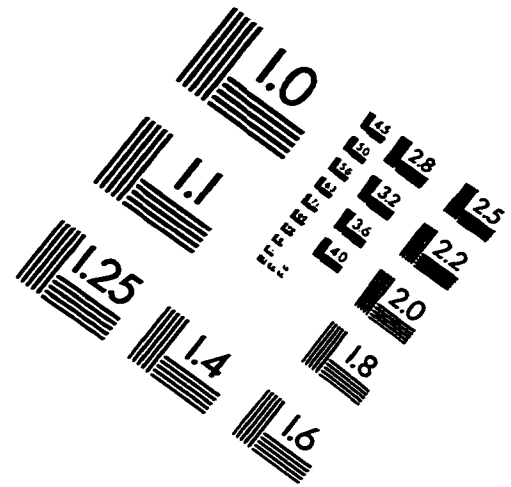
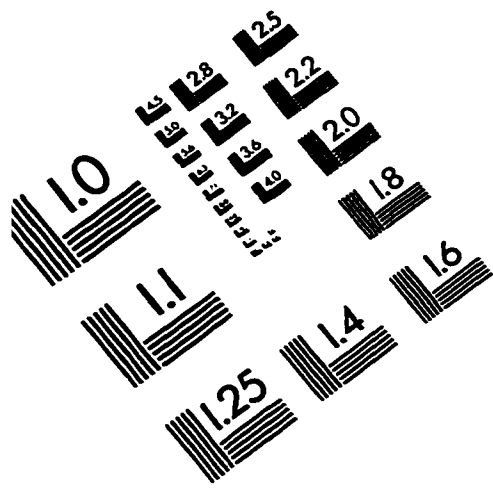
VITA

Diane M. Wrisley received a Bachelor of Science degree in Physical Therapy from the State University of New York at Buffalo in 1984. She began her career as a staff physical therapist at the City of Faith Medical Center in Tulsa Oklahoma. In 1986, she relocated to Richmond, Virginia to begin Masters level course work at Medical College of Virginia. While in Richmond she worked as a graduate teaching assistant at MCV and held staff physical therapy positions at Stuart Circle Hospital, Johnston-Willis Hospital and Rebound outpatient clinic. In 1989, she accepted a position as unit coordinator of the head injury unit at Helen Hayes Hospital in West Haverstraw, New York. She returned to Virginia in 1991 to accept a position as Director of Physical Therapy at Riverside Rehabilitation Institute. Following employment as an outpatient physical therapist at Therapy Center at Oyster Point, she accepted her current position as Coordinator of Vestibular Rehabilitation at DePaul Medical Center's Hearing and Balance Center in Norfolk, Virginia in 1994. She has been employed as Adjunct Assistant Professor at Old Dominion University in Norfolk, Virginia since 1995.

Ms. Wrisley was awarded board certification as a clinical specialist in Neurologic Physical Therapy in 1996. She presented a poster of "Student Clinic: A Model for Clinical Education" at APTA Scientific Meeting and Exposition in 1991. She presented "The Efficacy of Vestibular Rehabilitation" at the Virginia Physical Therapy Association annual conference in 1997 and was given the award for outstanding clinician presentation.

Department of Study: College of Health Sciences
School of Community Health Professions and Physical Therapy
Old Dominion University

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