Neuro Rehab- Module 1: Balance and Vestibular Dysfunction

Course Description:
Using a problem-solving approach based on clinical evidence, the text written by Darcy Umphred, PT, PhD, FAPTA, Neurological Rehabilitation, 6th Edition covers the therapeutic management of people with functional movement limitations and quality of life issues following a neurological event. It reviews basic theory and covers the latest screening and diagnostic tests, new treatments, and interventions commonly used in today’s clinical practice. This edition includes the latest advances in neuroscience, adding new chapters on neuroimaging and clinical tools such as virtual reality, robotics, and gaming.

Module 1: Balance covers chapter 22
Chapter 22: Balance and Vestibular Function

Methods of Instruction:
Online course available via internet

Target Audience:
Physical Therapists, Physical Therapy Assistants, Occupational Therapists, Occupational Therapy Assistants and Athletic Trainers.

Educational Level:
Intermediate

Prerequisites:
None

Course Goals and Objectives:
At the completion of this course, participants should be able to:
1. Recognize both central and peripheral sensory and motor components of the postural control system
2. List orthopedic problems that have a great impact on balance abilities
3. Differentiate between different balance tests and their advantages/disadvantages
4. Recognize how to perform different balance tests in a common clinical setting
5. Recognize the role balance confidence plays in ability
6. List examples of medical diagnoses and related impairments affecting balance
7. Recognize skilled movement optimal learning criteria
8. Identify variables when training to integrate postural control with locomotor skills
9. List intrinsic and extrinsic fall risk factors
10. Recognize the aim of intervention for fall prevention
11. Identify potential locations of lesions that may affect the vestibular system
12. Recognize characteristics of physiological double vision and its role in balance
13. Differentiate between types of nystagmus
14. Recognize movement diagnoses related to vestibular examination

Criteria for Obtaining Continuing Education Credits:
A score of 70% or greater on the written post-test
DIRECTIONS FOR COMPLETING

THE COURSE:

1. This course is offered in conjunction with and with written permission of Elsevier Science Publishing.
2. Review the goals and objectives for the module.
3. Review the course material.
4. We strongly suggest printing out a hard copy of the test. Mark your answers as you go along and then transfer them to the actual test. A printable test can be found when clicking on “View/Take Test” in your “My Account”.
5. After reading the course material, when you are ready to take the test, go back to your “My Account” and click on “View/Take Test”.
6. A grade of 70% or higher on the test is considered passing. If you have not scored 70% or higher, this indicates that the material was not fully comprehended. To obtain your completion certificate, please re-read the material and take the test again.
7. After passing the test, you will be required to fill out a short survey. After the survey, your certificate of completion will immediately appear. We suggest that you save a copy of your certificate to your computer and print a hard copy for your records.
8. You have up to one year to complete this course from the date of purchase.
9. If you have a question about the material, please email it to: info@advantageceus.com and we will forward it on to the author. For all other questions, or if we can help in any way, please don’t hesitate to contact us at info@advantageceus.com or 405-974-0164.
CHAPTER 22  Balance and Vestibular Dysfunction

LESLIE K. ALLISON, PT, PhD, and KENDA FULLER, PT, NCS

KEY TERMS
- activity limitation
- anticipatory postural adjustments
- automatic postural responses
- balance
- base of support
- body system problems
- center of gravity
- impairment
- limit of stability
- motor learning stages
- participation
- sensory conflict
- sensory environment
- strategies
- systems model or systems approach
- volitional postural movements

OBJECTIVES
After reading this chapter the student or therapist will be able to:
1. Describe both central and peripheral sensory and motor components of the postural control system.
2. List common postural control impairments found in clients with neurological problems.
3. List commonly used balance tests, and distinguish which are appropriate for clients at low, moderate, and high levels of function.
4. Differentiate how test results are used to identify body system impairments and activity limitations that limit participation.
5. Analyze the interaction of individual, task, and environmental factors that affect balance.
6. Describe how to plan and progress balance exercise programs to increase the use of, or compensation with, available sensory inputs.
7. Describe how to plan and progress balance exercise programs to facilitate anticipatory postural adjustments to prevent balance loss and provoke automatic postural responses to regain balance after unexpected disturbances.
8. Describe how to plan and progress balance exercise programs to increase the control of center of gravity in upright postures and during gait.
9. Describe how to increase the difficulty level of balance exercise programs in order to promote the automaticity of postural control during functional activities.
10. Identify and analyze the function of the vestibular system.
11. Describe how to facilitate adaptation and central nervous system reorganization to regain control of balance and decrease dizziness.
12. Describe patterns of recovery that influence choices of intervention.

Balance Function and Disorders
Leslie Allison, PT, PhD

No matter what the neurological diagnosis, a disease or injury that affects the nervous system is likely to compromise one or more of the postural control mechanisms. For example, clients with such diverse diagnoses as stroke, head trauma, spinal cord injury, peripheral neuropathy, multiple sclerosis (MS), Parkinson disease, cerebellar dysfunction, cerebral palsy, and Guillian-Barré syndrome all experience disequilibrium problems. One common thread among all these different medical diagnoses is the presence of balance impairments. Clients with different medical diagnoses may have the same balance impairments, and clients with the same medical diagnosis may have different balance impairments depending on which portions of the postural control system are involved. To optimally understand and manage balance problems, a test of each balance component and the interactive nature of the components is important. The traditional medical “diagnostic” model does not provide this information and is not the most beneficial model for planning balance rehabilitation interventions. The medical diagnosis is relevant: knowing whether deficits are permanent or temporary, and whether recovery or progressive decline is expected, is critical. This medical prognostic information will assist physical and occupational therapists in goal setting and intervention planning.

The International Classification of Functioning, Disability and Health (ICF) model described in Chapter 1 and illustrated in Figure 1-1 describes the interactions of body function and structure problems (impairments) and activity limitations as seen in clients with balance disorders, and how these functional activity limitations restrict an individual’s ability to participate in life situations, thus decreasing quality of life. Balance impairments negatively affect function, often reducing the individual’s ability to participate fully in life. These impairments often restrict activity levels, produce abnormal compensatory motor behavior, and may require devices for support or assistance from another person. Falls can result when imbalance is severe, leading to secondary injuries. To avoid these consequences and advance the functional status of clients, therapists should understand both the demands that various environments and functional tasks place on postural control systems and the impairments that may diminish the ability of those systems to respond adequately.

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BALANCE

Definitions of Balance

Balance is a complex process involving the reception and integration of sensory inputs and the planning and execution of movement to achieve a goal requiring upright posture. It is the ability to control the center of gravity (COG) over the base of support in a given sensory environment.6,7 The COG is an imaginary point in space, calculated biomechanically from measured forces and moments, where the sum total of all the forces equals zero. In a person standing quietly the COG is located just forward of the spine at approximately the S2 level. With movement of the body and its segments, the location of the COG in space constantly changes. The base of support is the body surface that experiences pressure as a result of body weight and gravity; in standing it is the feet, and in sitting it includes the thighs and buttocks. The size of the base of support will affect the difficulty level of the balancing task. A broad base of support makes the task easier; a narrow base makes it more challenging. The COG can travel farther while still remaining over the base if the base is large. The “shape” of the base of support will alter the distance that the COG can move in certain directions.

Any given base of support places a limit on the distance a body can move without either falling (as the COG exceeds the base of support) or establishing a new base of support by reaching or stepping (to relocate the base of support under the COG). This perimeter is frequently referred to as the limit of stability or stability limit.8,9 It is the farthest distance in any direction a person can lean (away from midline) without altering the original base of support by stepping, reaching, or falling.

Environmental Context

This biomechanical task of keeping the COG over the base of support is always accomplished within an environmental context, which is detected by the sensory systems. The sensory environment is the set of conditions that exist, or are perceived to exist, in the external world that may affect balance. Peripheral sensory receptors gather information about the environment, body position and motion in relation to the environment, and body segment positions and motions in relation to the self. Central sensory structures process this information to perceive body orientation, position, and motion and to determine the opportunities and limitations present in the environment. Gravity is one environmental condition that must be dealt with to remain stable. It is a constant condition for everyone except astronauts in space. Surface and visual conditions, however, may vary significantly and may be stable or unstable. Unstable surface conditions might include the subway, a sandy beach, a gravel driveway, or an icy parking lot. Common unstable visual conditions are experienced on mass transit, in crowds, or on a boat. Rapid head movements may render even a stable visual environment unusable for postural cues, and darkness may preclude the use of vision. The more stable the environment, the lower the demand on the individual for balance control. Unstable environments place greater demands on the postural control systems.

Balance is also affected by an individual’s intentions to achieve certain goals and the purposeful tasks that are undertaken. Volitional balance disturbances are self-initiated almost constantly, such as shifting from foot to foot, reaching for the telephone, or catching an object that is falling from a high shelf. Even reactions to involuntary balance disturbances, such as a slip or trip, are modified on the basis of the immediate task. A man carrying a bag of groceries who slips may drop the bag to reach with both hands and catch himself. If he is instead carrying his infant child, he may reach with only one hand or even take the fall if by doing so he can protect the infant from harm. Often in real life we perform several tasks at once, such as carrying a laundry basket while walking, or talking on a cellular phone while climbing a flight of stairs. When tasks are undertaken concurrently, attention must be divided between them, which may also affect balance abilities.

All these variables—the location of the COG, the base of support, the limit of stability, the surface conditions, the visual environment, the intentions and task choices—are inconstant, producing changing demands on the systems that control balance. The integrity and interaction of postural control mechanisms allow a wide range of movements and functions to be achieved without loss of balance.

HUMAN CONTROL OF BALANCE

Early studies of postural control mechanisms using selectively lesioned cats and primates focused on reflexive and reactive equilibrium responses that are relatively “hard-wired.”10 These valuable studies brought to light certain stereotypical motor responses to specific sensory stimuli, such as the crossed extension reflex or tonic neck reflexes. There is no doubt that these reflexive and reactive responses—for example, the vestibuloocular reflex (VOR) and the protective extension reactions—are foundational to normal postural control. However, the postural control system encompasses much more than these subcortically driven components. Balance abilities are heavily influenced by higher-level neural circuitry and other systems (e.g., cognitive, musculoskeletal), as well.11 In addition, the nervous system is influenced by and responsive to the demands placed on it by the tasks being accomplished and the environments in which those tasks are performed.12,13 All of these facets are included in a systems approach to dynamic equilibrium.10-12 Examination and intervention methods based on this systems model have consequently evolved.11,13

The Systems Approach

The dynamic systems model for dynamic equilibrium recognizes that balance is a result of interactions among the individual, the task(s) the individual is performing, and the environment in which the task(s) must be performed. These interactions are represented in Figure 22-1. Within the individual, both sensory inputs and processing systems (left side of figure) and motor planning and execution systems (right side of figure) are critical. Both peripheral components (lower part of figure) and central components (upper part of figure) of the systems are involved in the cycle. The cycle is driven both by purposeful choices of the individual (tasks) and by demands placed on the individual by the environment. Successful function of the sensory systems allows recognition of body position and motion in relation to self and the world. The desired outcome from the motor systems is the generation of movement sufficient to maintain balance and perform the chosen, goal-directed task(s).
Peripheral Sensory Reception

The three primary peripheral sensory inputs contributing to postural control are the bilateral receptors of the somatosensory, visual, and vestibular systems. Somatosensory receptors located in the joints, ligaments, muscles, and skin provide information about muscle length, stretch, tension, and contraction; pain, temperature, and pressure; and joint position. The feet, ankles, knees, hips, back, neck, and eye muscles all furnish useful information for balance maintenance. Somatosensory is the dominant sense for upright postural control and is responsible for triggering automatic postural responses (APRs). Somatosensory loss significantly impairs balance. Loss of peripheral somatosensation occurs in clients with loss or disease of or injury to the peripheral sensory receptors or afferent sensory nerves. Examples include clients with diabetic neuropathy, peripheral vascular disease, spinal cord injury, and amputation.

Visual receptors in the eyes perform dual tasks. Central (or foveal) vision allows environmental orientation, contributing to the perception of verticality and object motion, as well as identification of the hazards and opportunities presented by the environment. For example, a kayaker may see rocks in a stream as a hazard to be avoided, whereas a hiker who wants to cross the stream may see the same rocks as a welcome opportunity. Peripheral (or ambient) vision detects the motion of the self in relation to the environment, including head movements and postural sway. Peripheral vision is largely subconscious, whereas central visual inputs tend to receive more conscious recognition. Both are normally used for postural control. Vision is critical for feed-forward, or anticipatory, postural control in changing environments. This includes planning for functional movements such as reaching and grasping, and especially for successful navigation during gait. Vision loss also impairs balance. Loss of peripheral visual inputs occurs in clients with disease of or injury to the peripheral sensory receptors or afferent cranial nerves. Examples include clients with head injury involving temporal bone damage, acoustic neuroma, benign positional vertigo (BPV), or Meniere disease. For a comprehensive review of the vestibular system and vestibular disorders, please see the vestibular section of this chapter beginning on page 689.

Orientation to the wider environment, primarily from vision, allows feed-forward, or anticipatory, postural adjustments. Prior experience and high attentional capacity improve anticipatory postural adjustments significantly. Detection of head movement by the vestibular and cervical somatosensory systems and of body sway by somatosensory and peripheral visual systems provides feedback for APRs. Note that the better anticipatory abilities become, the fewer balance errors occur. Fewer balance errors mean fewer losses of balance and a reduced need to produce APRs.

Disease of or damage to any of the peripheral sensory receptors or afferent pathways impairs or removes the detection capabilities of the system, rendering sensory information unavailable for use in postural control. Many patients with neurological diagnoses have peripheral sensory impairments.
Central Sensory Perception

The brain processes all the environmentally available sensory information gathered by the peripheral receptors in varying degrees. This processing is usually referred to as multisensory integration or sensory organization. Central sensory structures function first to compare available inputs between two sides and among three sensory systems. The somatosensory system alone is unable to distinguish surface tilts from body tilts. Also, the visual system by itself cannot discriminate movement of the environment from movement of the body. The vestibular system by itself cannot tell if head movement through space is produced by neck motion or trunk and hip motion. Therefore the brain needs information from all three senses to correctly distinguish self-motion from motion in the environment.

How are sensory inputs from separate senses combined to form perceptions of position and motion? For example, consider the movement of turning your head to one side to look over your shoulder. When the head turns to one side, firing will increase in one vestibular organ and decrease proportionately in the other. This is known as push-pull function, and the information from each side is considered to “match.” With the same example, if the eyes are open while the head moves, the rate of the visual flow will be equal and the direction of the visual flow will be opposite to the rate and direction of information from the vestibular inputs. The muscles on one side of the neck will shorten and on the other side will stretch. The inputs from these three systems are congruent. If both sides and all three systems provide compatible inputs, the process of sensory organization is simplified.

When changes in the environment occur, the relative availability, accuracy, and usefulness of information from the three sensory systems may also change. Sensory organization also includes an adaptive process, called multisensory reweighting, that permits the CNS to prioritize the sources of sensory information when environmental conditions change. Available, accurate, and useful information is “upweighted,” whereas unavailable, inaccurate, or less-useful information is “downweighted.” For example, in dark environments, vision would be downweighted and somatosensory and vestibular information would be upweighted. This adaptive process is imperfect, however, and balance is not as well controlled when any sense must be downweighted as it is when all three senses are available and accurate. Individuals with peripheral sensory loss or central sensory processing deficits may have difficulty reweighting quickly and fully. This impairs their ability to adapt to, and remain stable in, changing environments.

Sensory conflict can arise when information between sides or between systems is not synchronous. Sensory organization processing then becomes more complex because the brain must then recognize any discrepancies and select the correct inputs on which to base motor responses. The vestibular system may be used as an internal reference to determine accuracy of the other two senses when they conflict. For example, a driver stopped at a red light suddenly hits the brake when an adjacent vehicle begins to roll. Movement of the other car detected by the peripheral visual system is momentarily misperceived as self-motion. In this situation, the vestibular and somatosensory systems do not detect motion, but the forward visual flow is interpreted as backward motion. Because the brain failed to suppress the (mismatched) visual inputs, the braking response was generated.

When the brain recognizes that the information coming from one sensory input is inaccurate or unavailable, as is the case when somatosensory information is diminished post-stroke, it must depend more on the remaining senses (in this case, vision and vestibular system) to determine position and motion in space. The brain then compares and uses information from senses it considers accurate for balance. An individual with the problem just described may compensate for the loss of somatosensory function by becoming visually dependent for balance during movement. If vision subsequently also becomes disrupted as this client ages, his ability to orient in space will be further compromised. This will impair balance and increase risk of falls.

Activities or environments that create sensory conflict or demand sensory resolution become more difficult to manage when the vestibular system is deficient or underused. These situations, such as going down stairs, riding escalators or elevators, walking on uneven ground, and making quick
turns, are often avoided. When sensory conflicts cannot be resolved rapidly, dizziness or motion sickness occurs.

Intrinsic central sensory processing impairments also can produce sensory conflict. An adult hemiplegic patient with pusher syndrome illustrates an inability to integrate visual, vestibular, and somatosensory inputs for midline orientation. Within a single system, discrepancies between the sides are also problematic. Unequal firing from opposite sides of the vestibular system, as in unilateral vestibular hypofunction, produces a mismatch that is subsequently interpreted as head rotation when head movement does not occur. This spinning sensation is known as vertigo. Vertigo is resolved if the brain is able to adapt to the mismatch. For additional information on vertigo, refer to the section on the vestibular system.

Finally, the central processing mechanisms combine any available and accurate inputs to answer the questions “Where am I?” and “How am I moving?” This includes both an internal relation of the body segments to one another (e.g., head in relation to trunk, trunk in relation to feet) and an external relation of the body to the outside world (e.g., feet in relation to surface, arm in relation to handrail). CNS disease or trauma involving the parietal lobe may impair these processing mechanisms so that even available, accurate sensory inputs are not recognized or incorporated into determinations of position and movement. Impairments of central sensory processing may occur after stroke, head trauma, tumors, or aneurysms; with disease processes such as MS; and with aging.

Central Motor Planning and Control

Whereas sensory processing allows the interaction of the individual and the environment, motor planning underlies the interaction of the individual and the task. Aside from reflexive activity such as breathing and blinking, most motor actions are voluntary and occur because some goal is to be achieved. That is not to say that reflexes occur separately from volitional movements; for example, the vestibulococular reflex is active concurrently with visual tracking activity, but most actions occur because of some purposeful intent. These task intentions precede motor actions. Wrist and hand movements vary depending on what is to be grasped (a cup versus a doorknob); foot placement and trunk position vary depending on what is to be lifted (a heavy suitcase versus a laundry basket). The initiation of volitional motor actions depends on intention, attention, and motivation.

Once an objective (“Where do I want to be?” “What do I want to do?”) has been chosen, the next step in motor planning is to determine how to best accomplish the goal given the many options that are potentially available. For example, when the task demands fine skills or accuracy, the dominant hand is preferred; when the task involves lifting a large or heavy object, both hands are preferred. In addition to which limbs, joints, and muscles will be used, motor planning also adjusts the timing, sequencing, and force modulation. This can be demonstrated in various reaching tasks. Reaching to remove a hot item from the oven will occur slowly, whereas reaching to put an arm through a sleeve will occur more quickly. Optimal motor plans are developed with knowledge of self (abilities and limitations), knowledge of task (characteristics of successful performance), and knowledge of the environment (risks and opportunities).

The motor plan must be transmitted to the peripheral motor system to be enacted. A copy of the intended movement plan is sent to the cerebellum during the transmission. When the movement begins, incoming sensory inputs (feedback) about the actual movements and performance outcome are compared with the intended movements and performance outcome. Movement errors (the difference between the intended and the actual movement) and performance errors (desired goal not achieved) are detected, and plans for correction are then formed and transmitted. This process of error detection and error correction is the foundation of motor learning.

Clients with CNS disorders often have central motor planning and control system problems. After a stroke, clients may have hypertonus and poor reciprocal inhibition; clients with head trauma may have difficulty initiating or ceasing movements; clients with Parkinson disease exhibit bradykinesia; and those with cerebellar ataxia display modulation problems.

Peripheral Motor Execution

Movement is accomplished through the bilateral joints and muscles. Normal range of motion (ROM), strength, and endurance of the feet, ankles, knees, hips, back, neck, and eyes must be present for the execution of the full range of normal balance movements. Decreased ankle dorsiflexion ROM, for example, restricts the forward limits of stability. Strength deficits are a primary cause of movement abnormalities in both central and peripheral nervous system disorders. In addition, weakness may be the result of force modulation deficits or disuse. Balance is directly affected by loss of strength. For example, weakness of the hip extensors and abductors will impede successful use of a hip strategy for upright trunk control. Initially adequate toe clearance may diminish with fatigue. Many clients with neurological issues also have stiffness and contractures as a result of persistent weakness or hypertonus. Restrictions in ROM also limit balance abilities.

The ability to achieve static postural alignment, although necessary for normal balance, is not sufficient to allow volitional functions. Adequate strength (to control body weight and any additional loads) through normal postural sway ranges is needed to permit dynamic balance activities such as reaching, leaning, and lifting. Postural control demands are increased during gait because the forces of momentum and the interaction between recruitment, timing, and velocity also must be regulated. Traditionally considered orthopedic problems, deficits in strength, ROM, posture, and endurance have a great impact on balance abilities. Attention must be given to these musculoskeletal system problems in examination of and intervention for clients with neurological diagnoses.

Influence of Other Systems

Balance abilities are also influenced by other systems. Attention, cognition and judgment, and memory are critical for optimal balance function and are often impaired in hemiplegic and head-injured clients as well as those who have progressive neurological disorders. Attentional deficits reduce awareness of environmental hazards and opportunities, interfering with anticipatory postural control. When balance is threatened, an inability to allocate attention to the necessary task of balance
versus a secondary, less necessary task increases the risk of falls. Cognitive problems such as distractibility, poor judgment, and slowed processing also increase the risk of falls. Memory loss may preclude recall of safety measures. Depression, emotional liability, agitation, or denial of impairments also can increase the risks for loss of balance. In addition to having a direct impact on balance abilities themselves, these cognitive and behavioral problems impede motor learning processes, which are crucial for the relearning of balance skills.

### Constant Cyclic Nature

The systems model of postural control previously presented illustrates the constant cycle that simultaneously occurs at many levels. Attention and intention allow feed-forward processing for active sensory search of the environment and motor planning, both of which are needed for anticipatory postural control. Movements are initiated and executed with resultant sensory experiences and error detection, or feedback. Successful movements are repeated and refined; unsuccessful ones are modified. The nature of this cycle presents the clinician with opportunities for intervention after the appropriate examination of sensory, motor, and cognitive functions. Through feedback and practice, balance abilities can improve.  

### Motor Components of Balance

#### Reflexes

Many levels of neuromuscular control must be functioning to produce normal postural movements. At the most basic level, reflexes and righting reactions support postural orientation. The VOR and the vestibulospinal reflex (VSR) contribute to orientation of the eyes, head, and body to self and environment.  

When motion of the head is identified by the semicircular canals, it triggers a response within the oculomotor system called the vestibuloocular reflex. This causes the eyes to move in the opposite direction of the head but at the same speed. Stimulation of the otoliths drives the eyes to respond to linear head movement. Quick movements of the head will trigger the VOR.  

The VOR allows the coordination of eye and head movements. When the eyes are fixed on an object while the head is moving, the VOR supports gaze stabilization. Visuo-ocular responses often work concurrently with the VOR. They permit “smooth pursuit” when the head is fixed while the eyes move and visual tracking when both the eyes and the head move simultaneously.  

The VSR helps control movement and stabilize the body. Both the semicircular canals and the otoliths activate and modulate muscles of the neck, trunk, and extremities after head movement to maintain balance. The VSR permits stability of the body when the head moves and is important for the coordination of the trunk over the extremities in upright postures. Righting reactions support the orientation of the head in relation to the trunk and the head position relative to gravity and include labyrinthine head righting, optical head righting, and body-on-head righting.  

#### Automatic Postural Responses

At the next level, automatic postural responses operate to keep the COG over the base of support. They are a set of functionally organized, long-loop responses that act to keep the body in a state of equilibrium. Functionally organized means that the responses, although stereotypical, are matched to the perturbing stimulus in direction and amplitude. If the stimulus is a push to the right, the response is a shift to the left, toward midline. The larger the stimulus, the greater the response. Automatic postural responses always occur in response to an unexpected stimulus and are typically triggered by somatosensory inputs. Because they occur rapidly, in less than 250 ms, they are not under immediate volitional control.

Four automatic postural responses have been described. Ankle strategy describes postural sway control from the ankles and feet. The head and hips travel in the same direction at the same time, with the body moving as a unit over the feet (Figure 22-2, A). Muscle contractile patterns are from distal to proximal (i.e., gastrocnemius, hamstrings, paraspinals). This strategy is used when sway is small, slow, and near midline. It occurs when the surface is broad and stable enough to allow pressure against it to produce forces that can counteract sway to stabilize the body. Ankle strategy is typically used to control anterior-posterior sway, because most of the degrees of freedom at the ankle are in this direction.

Hip strategy involves postural sway control from the pelvis and trunk. The head and hips travel in opposite directions, with body segment movements counteracting one another (Figure 22-2, B). Muscle contractile patterns are from proximal to distal (i.e., abdominals, quadriceps, tibialis anterior). This strategy is observed when sway is large, fast, and nearing the limit of stability or if the surface is too narrow or unstable to permit effective counterpressure of the feet against the surface. Hip strategy is used to control both anterior-posterior and medial-lateral sway. Hip strategy in the medial-lateral direction involves weight shifts from foot to foot; any client with difficulty weight-shifting quickly and accurately will have difficulty with medial-lateral hip strategy.

Suspensory strategy involves a lowering of the COG toward the base of support by bilateral lower-extremity flexion or a slight squatting motion (Figure 22-2, C). By shortening the distance between the COG and the base of support, the task of controlling the COG is made easier. This strategy is often used when a combination of stability and mobility is required, as in windsurfing.

Stepping and reaching strategies involve steps with the feet or reaches with the arms in an attempt to reestablish a new base of support with the active limb(s) when the COG...
has exceeded the original base of support (Figure 22-2, D). A successful stepping strategy is the best way to avoid a fall after a slip or trip.

Misconceptions about these APR strategies are common. First, these strategies do not function in daily life as separately as they are described in the early research literature. In quiet standing, for example, frequency analysis of unperturbed postural sway in healthy adults reveals that both ankle and hip strategies occur in combination, simultaneously. In perturbation studies, mixed use of strategies is often seen unless the perturbation is clearly below or above certain-sized thresholds. Second, these strategies occur in response to disturbances from all directions, not just in pure anterior-posterior or medial-lateral directions. Third, although these strategies are stereotypical in humans, great individual variation in strategy selection and performance comes from other influential factors. For example, many people use stepping strategy for most perturbations unless specifically instructed not to step or unless the conditions do not permit a step. An anxious person may reach or step much sooner than a relaxed person with similar physical deficits. Last, all these strategies do not occur in sequence with every balance disturbance. In other words, individuals normally do not try ankle strategy and wait until it fails before trying hip strategy, then wait until it fails before trying stepping strategy (although early learning may involve such exploration). Because these responses must occur extremely rapidly to prevent balance loss, such a sequential approach would be inefficient and ineffective. Instead, the normal response is the emergence of the single strategy best suited to the particular perturbation, the limitations of the individual, and the conditions in the environment.

Abnormal use of automatic postural responses is often observed in individuals with neurological disorders. Clients with vestibular deficits typically rely on ankle strategy, which permits the head to remain aligned with the body and sustains congruence between vestibular and somatosensory inputs. Use of hip strategy may be modified or limited because when the head is moving in the opposite direction as the COG, vestibular and somatosensory inputs are not congruent. Activities that require use of hip strategy, such as standing in tandem or on one leg, can be a problem for clients with bilateral vestibular loss or an uncompensated vestibular lesion. However, some cases involve excessive use of hip strategy on a level surface (when an ankle strategy would suffice). This may reflect abnormal integration of the somatosensory and vestibular information. If peripheral somatosensation is impaired, as in diabetic neuropathy, or central sensory weighting of somatosensory inputs is inadequate, hip strategy may dominate.

Clients with somatosensory loss, distal lower extremity weakness or hypertonus, restricted ankle ROM, and/or reduced limits of stability typically rely on hip strategy. This occurs because the client cannot feel the surface or the feet well enough to modulate foot pressure against the surface, because the person cannot generate sufficient force against the surface with the ankle muscles, or because restricted ankle ROM prevents COG sway. The use of hip strategy is normal when the COG is at or near the limits of stability and a step is either not possible or not desired.

When the hip or ankle strategy is not efficient enough to control the movement of the center of pressure, or if conditions and instructions permit a stepping response, stepping strategy may be preferred. Individuals who are fearful of falling often perceive even slight body sway as threatening instability. They may use stepping and reaching strategies exclusively whether or not these “rescue” strategies are actually necessary.

**Anticipatory Postural Adjustments**

Anticipatory postural adjustments are similar to automatic postural responses, but they occur before the actual disturbance. If a balance disturbance is predicted, the body will respond in advance by developing a “postural set” to counteract the coming forces. For example, if an individual lifts an empty suitcase, they might cause excessive movement and brief instability. Failure to produce these anticipatory adjustments increases the risk of sudden balance loss, creating the need to use rapid, reactive automatic postural responses to prevent a fall. For clients with deficits in reaction time or automatic postural responses, superior use of anticipatory postural control can help the client avoid the unexpected perturbations that make automatic postural responses necessary.

In balance laboratories, anticipatory postural adjustments are studied using electromyography so that muscle activity before observable movement can be measured. In the clinic, problems with anticipatory adjustments may be observed when the client fails to counteract a predicted disturbance, such as “don’t let me push you backward,” or fails to integrate postural control tasks during other activities, such as the inability to step smoothly over an anticipated obstacle during gait or inability to maintain sitting balance when both arms are intentionally lifted overhead.

**Volitional Postural Movements**

Volitional postural movements are under conscious control. Weight shifts to allow an individual to reach the telephone or put the dishes in the dishwasher, for example, are self-initiated disturbances of the COG to accomplish a goal. Volitional postural movements can range from simple weight shifts to complex balance skills of skaters and gymnasts. They can occur after a stimulus or be self-initiated. Volitional postural movements can occur quickly or slowly, depending on the goal at hand. The more complex or unfamiliar the task, the slower the response time. Use of a variety of movements that might successfully achieve a goal is possible. Volitional postural movements are strongly modified by prior experience and instruction. Automatic and anticipatory postural responses allow the continuous unconscious control of balance, whereas volitional postural movements permit conscious activity. This level of postural motor control is the most frequently tested and treated in clinical practice, but it is by no means sufficient by itself to produce normal balance.

**CLINICAL ASSESSMENT OF BALANCE**

**Objectives of Testing**

When present, activity limitations need to be identified and measured. Functional scales are typically used to determine the presence and severity of these limitations, not necessarily why those limitations exist. From these functional tests, decisions can be made about whether to treat and, if so, what
tasks need to be practiced. If treatment is indicated, clinicians must make judgments about what to treat. Further testing to identify and measure impairments is then necessary to know what systems are involved. A comprehensive evaluation of balance includes both functional and impairment tests.12

No single quick-and-easy test of balance can adequately cover the many multidimensional aspects of balance, although many such tests have great value as screening tools. However, a comprehensive test battery, called the Balance Evaluation Systems Test (BESTest), based on the systems model has been developed that provides clinicians with a thorough examination at the impairment level (Figure 22-3).31 The BESTest takes more time to administer than, for example, a single-leg stance test, but results from the BESTest give the clinician a far more complete and accurate picture of the client’s balance impairments than any single-item test or screening test can. Armed with these results, the clinician can develop interventions specifically targeted to the impaired systems. For clients whose primary problems include imbalance, the clinician’s investment of time to perform this comprehensive test battery yields a valuable outcome. A shorter version of this test, the mini-BESTest, has subsequently been published.32 It takes less time to administer but likewise provides a less complete picture of the client’s balance systems. Specifically, it does not include any items from the biomechanical constraints or stabilities limits categories. Even so, it is superior to single-item tests or screening tests that are not based on the systems model and do not identify balance system impairments that should be addressed in the intervention plan.

No single, simple test for balance is possible because balance is such a complex sensorimotor process.33 Many relatively simple balance tests exist, but not all tests are appropriate for all clients. Different tests may be needed to answer specific questions. For example, several good tests have been developed to determine the risk of falls in elderly people. These would be insufficient to discern whether an injured dancer can resume practice or an injured roofer is ready to return to work. Clinicians should understand the advantages and limitations of different balance tests to be able to select appropriate evaluative tools.

In general, a balance test will not be useful unless it sufficiently challenges the postural control system being tested. Tests for stability (“static balance”) are appropriate for clients who are having difficulty simply finding midline or holding still in sitting or standing. They are of much less value for clients with higher-level abilities. Conversely, single-leg stance tests or sensory tests with a foam surface may be far too difficult for clients with lower-level abilities to perform.

A word of caution about interpreting test results is indicated. Most clinical tests rely on observations of motor behavior to arrive at some conclusion about what systems have problems and how they affect movement. Abnormal motor behavior has many causes, and clinicians should be careful before concluding that an observed behavior is caused by problems in a certain system. For example, the Romberg test is commonly assumed to test the use of vestibular inputs. Yet during the test, both somatosensory and vestibular inputs are (normally) used for balance control. If balance control is deficient, is the vestibular system necessarily the culprit? Could somatosensory system deficits also result in a poor test result? Or, alternatively, because the Romberg test is performed with feet together, what effect would hip weakness have on the ability to stand with a narrowed base of support? When using a test whose results may be altered by problems in more than one system, any relevant system should be evaluated. If multiple system deficits exist, and they often do in clients with neurological conditions, then use caution in making “commonly assumed” conclusions on the basis of clinical test results.

Because so many balance tests are available, several questions must be asked to determine whether a test is appropriate for use.32 For what purpose and population was the test designed? Can that test be used legitimately for a different purpose or with a different population? Is it valid? Is it repeatable by different examiners or by the same examiner multiple times? Are results reliable? In what populations are they reliable? What is the threshold for this test—that is, how large must performance changes be before this test can detect them? Are normative data available for comparison? These questions are being investigated but have not yet been answered for many of the clinical balance tests commonly used by therapists with the many different neurological populations they treat. Some of the evidence already reported may be frustrating to clinicians. For example, the Timed Up-and-Go test (TUG) predicts falls in community-dwelling older adults but not in acute-care hospital populations.34,35 For several balance tests such as the Functional Reach Test, the Berg Balance Scale, and others, the cutoff scores used for accurate prediction of falls in clients with Parkinson disease are different from the cutoff scores used in older adults without Parkinson disease.36 These examples make it clear that clinicians must understand their clients and the characteristics of the various balance tests in order to select the most appropriate tests and interpret test results for each client.

Types of Balance Tests
Balance tests can be grouped or classified by type. Different types of tests measure different facets of postural control (Table 22-1). Quiet standing (static) refers to tests in which the client is standing and the movement goal is to hold still. Disturbances to balance, called perturbations, may or may not be applied. Active standing (dynamic) tests also position the patient standing, but the movement goal involves voluntary weight shifting. Sensory manipulation tests use altered surface and visual conditions to determine how well the CNS is using and reweighting sensory inputs for postural control. Functional balance, mobility, and gait scales involve the performance of whole-body movement tasks, such as sitting to standing, walking, and stepping over objects. A few test batteries offer a combination of the preceding tests. The BESTest is the most comprehensive test battery to date. Dual-task tests have been developed to examine the effect of concurrent activities and divided attention on balance and mobility performance. A commonly accepted test for sitting balance in adults is not yet available, although clients with neurological problems often need sitting balance retraining in early stages. Clinicians typically modify standing tests or pediatric sitting tests to assess sitting balance in adult clients with neurological conditions. For example, the Functional Reach Test has been used to measure excursion in seated individuals with spinal cord injuries.37
### I. Biomechanical Constraints

1. Base of support
2. CoM alignment
3. Ankle strength and ROM
4. Hip/trunk lateral strength
5. Sit on floor and stand up

### II. Stability Limits/Verticality

6. Sitting verticality (left and right) and lateral lean (left and right)
7. Functional reach forward
8. Functional reach lateral (left and right)

### III. Anticipatory Postural Adjustments

9. Sit to stand
10. Rise to toes
11. Stand on one leg (left and right)
12. Alternate stair touching
13. Standing arm raise

### IV. Postural Responses

14. In-place response, forward
15. In-place response, backward
16. Compensatory stepping correction, forward
17. Compensatory stepping correction, backward
18. Compensatory stepping correction, lateral (left and right)

### V. Sensory Orientation

19. Sensory integration on balance (modified CTSIB). A: Stance on firm surface EO; B: stance on firm surface EC; C: stance on foam EO; D: stance on foam EC
20. Incline, EC

### VI. Stability in Gait

21. Gait, level surface
22. Change in gait speed
23. Walk with head turns, horizontal
24. Walk with pivot turns
25. Step over obstacles
26. Timed “Get up & Go” Test
27. Timed “Get up & Go” Test with dual task

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**Figure 22-3** Balance Evaluation Systems Test (BESTest) with modifications of both long and short forms. Short form identified by 14 components shown in BOLD. CoM, Center of mass; CTSIB, Clinical Test of Sensory Integration on Balance; EC, eyes closed; EO, eyes open; ROM, range of motion. (Data from Horak FB, et al: *Phys Ther* 89:484–498, 2009.)
TABLE 22-1  ■  TYPES OF BALANCE TESTS

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TESTS</th>
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<tbody>
<tr>
<td>Quiet standing (with or without perturba-</td>
<td>Romberg</td>
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<td>tion)</td>
<td>Sharpened Romberg or tandem</td>
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<td></td>
<td>One-legged stance test (OLST)</td>
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<td></td>
<td>Timed stance battery</td>
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<td></td>
<td>Postural sway</td>
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<td></td>
<td>Nudge or push</td>
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<td></td>
<td>Postural Stress Test</td>
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<td></td>
<td>Motor Control Test</td>
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<tr>
<td>Active standing</td>
<td>Functional Reach Test</td>
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<td></td>
<td>Multi-Directional Reach Test</td>
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<tr>
<td></td>
<td>Limits of stability</td>
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<tr>
<td>Sensory manipulation</td>
<td>Sensory Organization Test (SOT)</td>
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<td></td>
<td>Clinical Test of Sensory Interaction and Balance (CTSIB)</td>
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<tr>
<td>Vestibular</td>
<td>Vertiginous positions</td>
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<td></td>
<td>Hallpike-Dix maneuver</td>
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<td>Nystagmus</td>
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<td>Semicircular canal function</td>
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<td>Visual-vestibular interaction</td>
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<td>Visual acuity</td>
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<td>Oculomotor tests</td>
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<td>Fukuda Stepping Test</td>
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<td>Dizziness Handicap Inventory</td>
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<tr>
<td>Functional scales</td>
<td>Berg Balance Scale</td>
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<tr>
<td></td>
<td>Timed Up-and-Go Test</td>
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<tr>
<td></td>
<td>Tinetti Performance-Oriented Assessment of Balance</td>
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<td></td>
<td>Tinetti Performance-Oriented Assessment of Gait</td>
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<tr>
<td></td>
<td>Gait Assessment Rating Scale (GARS)</td>
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<td>Dynamic Gait Index</td>
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<td></td>
<td>Functional Gait Assessment</td>
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<tr>
<td>Combination test batteries</td>
<td>Fugl-Meyer Sensorimotor Assessment of Balance Performance</td>
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<tr>
<td>Dual task</td>
<td>Stops walking when talking</td>
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<td></td>
<td>Multiple Tasks Test</td>
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**Quiet Standing**

The classic Romberg test was originally developed to "examine the effect of posterior column disease upon upright stance."38 The client stands with feet parallel and together and then closes the eyes for 20 to 30 seconds. The examiner subjectively judges the amount of sway. Quantification of sway can be accomplished with a videotape, forceplate, or, more recently, accelerometer.59,60 Excessive sway, loss of balance, or stepping during this test is abnormal. The sharpened Romberg,38 also known as the tandem Romberg, requires the client to stand with feet in a heel-to-toe position and arms folded across the chest, eyes closed for 60 seconds. Often four trials of this test are timed with a stopwatch, for a maximum score of 240 seconds.

One-legged stance tests (OLSTs) are commonly used.38,44 Both legs must be alternately tested, and differences between sides are noted. The client stands on both feet and places hands on the hips or crosses the arms over the chest, then picks up one leg and holds it with the hip in neutral and the knee flexed to 90 degrees. The lifted leg may not be pressed into the stance leg. This test is scored with a stopwatch. Five 30-second trials are performed for each leg (alternating legs), with a maximum possible score of 150 seconds per leg. Normal young subjects are able to stand for 30 seconds, but this may not be a reasonable expectation for frail older clients.38

In both the Romberg test and the OLST, problems in sensory organization processes can be observed. To determine how much of the stability is achieved through visual stabilization, each test can be repeated with eyes closed. The client with visual dependency for balance will often have an immediate loss of balance when the eyes are closed. (Remember, visual dependency may be a sign of somatosensory or vestibular loss, or both.) As noted earlier, the client with somatosensory or vestibular loss may have difficulty producing the hip strategy necessary to perform these tasks.

A battery of timed stance tests has been developed by Bohannon and Leary.42 This set of tests varies the foot position (apart, together, tandem, and single leg) and the availability of visual information (eyes open and closed) to produce eight different combinations. Maintenance of balance in each condition is timed for a maximum of 30 seconds; the assigned score is the total number of seconds that balance could be maintained. The best possible score on this test is 240 seconds. This test is reliable, valid, and sensitive to change over time.42

A related test is the Balance Error Scoring System, or BESS test, which was developed for use with athletes to screen for concussion effects.43,44 The original BESS test involved three stance positions (double-leg stance with feet together, single-leg stance, tandem stance) on two surfaces (firm and foam), thus providing six conditions. The eyes are closed in all conditions. Each trial is 20 seconds in duration. The examiner observes and counts the number of balance errors that are made in each condition. The six observed errors include hands lifted off waist; opening eyes; step, stumble, or balance loss; moving a hip past 30 degrees of abduction; lifting the forefoot or heel; and remaining out of the test position for more than 5 seconds. If more than one error occurs at the same time, for example, opening eyes and hands off waist, only one error is counted. When measured in high-level young adults, the reliability of this test improved with the removal of the double-leg stance condition, which produced few to no errors in this high-functioning population, and the addition of three trials in each of the remaining four conditions. The modified BESS test thus includes only four conditions.45 This test has not been investigated for use in traditional neurological rehabilitation populations.

Objective postural sway measures can be obtained by computerized force plates (Figure 22-4) or wearable accelerometers (Figure 22-5).42-48 The client is asked to adopt a standardized foot placement if possible (this varies by manufacturer) and to stand quietly with arms at the sides or hands on hips for 20 or 30 seconds. Sway with both eyes open and eyes closed is commonly measured. Graphic and numerical quantification is provided. Normative data may be provided. These more technical measures are able to detect more subtle problems and are more sensitive to change in performance after treatment than are rating scales or timed measures.
Automatic postural responses are assessed by the client’s response to perturbations. It is imperative that clinicians include APR testing in their balance assessment because APRs are the motor responses necessary to prevent loss of balance and falls. The push-and-release test is a clinically useful method with a five-point ordinal rating scale. Testing for ankle and hip strategies (“in-place” strategies) requires that the clinician (1) place his or her hands on the front or back of the patient’s shoulders, (2) ask the patient to remain still and centered by resisting the pressure applied by the hands (producing isometric muscle activity), (3) watch for the toes or heels to begin to raise slightly (the clinician increases pressure until this occurs), then (4) suddenly release the push. Both forward and backward directions are tested; the clinician always stands where he or she can support the client in case of balance loss. Testing for stepping strategy follows the same concept but is performed differently. Instead of keeping the client’s COG at midline, the client leans his or her weight into the clinician’s hands, shifting the COG away from midline toward the outer limit of stability before the release. The correct client response is to step to reestablish a new base of support underneath the new position of the COG. Forward, backward, and both lateral directions are tested. When nudge or push tests are performed predictably (i.e., “don’t let me push you backward”), this is assessment of anticipatory postural control. When the release happens unpredictably (no cues, unpredictable timing), automatic postural responses can be assessed. Perturbations of different strengths from multiple different directions should be given.

Figure 22-4 ■ Graphic and numerical postural sway measures using a computerized force plate system. Top left, Normal subject, eyes open. Top right, Healthy subject, eyes closed. Bottom left, Client with Parkinson disease, eyes open. Bottom right, Client with Parkinson disease, eyes closed. (Reprinted with permission from NeuroCom International, Clackamas, Ore.)

Figure 22-5 ■ A, A wearable accelerometer for motion detection that can be used to measure postural sway and other physical motions. B, The accelerometer worn in a belt at the L5-S1 level. C, Postural sway data recorded by the accelerometer. (Photographs courtesy McRoberts B, The Hague, The Netherlands.)
The Motor Control Test (MCT) is a computerized test of automatic postural responses that perturbs the client through surface displacement (Figure 22-6, B). The client stands on a dynamic (movable) forceplate with feet parallel and arms at sides. The support surface rapidly translates (slides) forward or backward. This surface displacement results in a rapid shift in the relation between the COG and the base of support. The expected responses are directionally specific (to the direction of the stimulus) forces generated against the surface to bring the COG back to the center. Response latencies, strength, and symmetry are measured. Normative data are available. This test can be used to look for abnormal stepping strategies when failure to select hip strategy occurs. The MCT is the most standardized and reliable test of automatic postural responses, but it is not widely used because it requires computerized equipment.

Active Standing

Volitional control of the COG is evaluated by asking the client to make voluntary movements that require weight shifting. The Functional Reach Test was developed for use with older adults to determine risk of falls. The client stands near a wall with feet parallel. Attached to the wall at shoulder height is a yardstick. The client is asked to make a fist and raise the arm nearest the wall to 90 degrees of shoulder flexion. The examiner notes the position of the fist on the yardstick. The client is then asked to lean forward as far as possible, and the examiner notes the end position of the fist on the yardstick (Figure 22-7). Beginning position is subtracted from end position to obtain a change unit in inches. Three trials are performed. Normative data are available, and the test is reliable. However, the standard error of measurement for this test may be as high as 2 inches, meaning that a change in score of less than 2 inches cannot be attributed to clinical improvement because it may reflect only measurement error. Subsequent studies have not shown that this test is useful for fall prediction.

One serious limitation of the Functional Reach Test is that it measures sway in only one direction (forward). An expansion of this test has been devised to measure sway in four directions. The multidirectional reach test is conceptually equivalent but measures sway anteriorly, posteriorly, and laterally to both sides. This test should provide a more comprehensive picture of volitional COG control limitations. Validity and mean values have been established for community-dwelling older adults.

The limits of stability test uses a computerized forceplate to measure postural sway away from midline in eight directions. Clients assume a standardized foot position and control a cursor on the computer monitor by shifting their weight. They are asked to move the cursor from midline to eight targets on the screen (Figure 22-8). Measures include movement velocity, directional control (path sway), measures...
of excursion (length of the trajectory of the COG), and reaction time. This test should be performed once for familiarization, then a second time for scoring purposes. Second and subsequent tests are reliable. Normative data are available.

A very challenging test used primarily in athletic populations is the Star Excursion Balance Test (SEBT) (Figure 22-9). The SEBT could be used, for example, in high-level traumatic brain injury (TBI) clients who require more demanding test conditions. However, although there is evidence for the validity and reliability of this test in orthopedic populations, as yet this test has not been investigated for use in neurological populations. The SEBT is in concept a lower-extremity functional reach test, requiring single-leg stance on one leg and a reach with the other leg. The original SEBT included eight directions; currently the SEBT is typically performed in three directions: center-forward, right-rear, and left-rear. Three tape measures are taped to the floor, radiating out from the same center point. The two rear tape measures are at a 45-degree angle from the center line. The client stands on one foot with the great toe on the center point, then reaches the maximum distance away from the center with the lifted foot. The distance is recorded by the examiner. This is done in all three directions, with the lifted leg having to cross behind the stance leg to reach to the opposite-side rear tape. Six practice trials in each direction are given before recording scores to eliminate a learning effect, although recent evidence suggests four practice trials may be sufficient. Three scored trials in each direction are performed. Both legs are tested.

**Figure 22-8** Graphic postural sway measures from the limits of stability test using a computerized force plate system (numerical measures not shown). Clients are asked to move away from and return to midline. **A**, Subject with normal postural sway. **B**, Hemiplegic client on initial evaluation. **C**, Hemiplegic client on discharge evaluation. (Reprinted with permission from NeuroCom International, Clackamas, Ore.)

**Sensory Manipulation**

Sensory inputs play a critical role in postural control, but few tests to measure their use to produce a balance performance outcome have been developed. The Sensory Organization Test (SOT) uses a computerized, movable forceplate and movable visual surround to alter the surface and visual environments systematically. The client stands on the forceplate with feet parallel and arms at the sides and is asked to stand quietly. Three 20-second trials under each of six sensory conditions are performed (Figure 22-10). In conditions one, two, and three the support surface (forceplate) is fixed. During conditions four, five, and six the support surface is sway referenced to the sway of the client in a 1:1 ratio. This responsive surface movement maintains a near-constant ankle joint angle despite body sway, rendering the somatosensory information from the feet and ankles inaccurate for use in balance maintenance. Visual inputs are undisturbed in conditions one and four. Vision is absent (eyes are closed) in conditions two and five. The movable visual surround is sway referenced in conditions three and six. This responsive visual surround movement maintains a near-constant distance between the eyes and the visual environment despite body sway, rendering visual inputs from
The Sensory Organization Test determines the relative reliance on visual, vestibular, and somatosensory inputs for postural control using computerized dynamic posturography. (From Hasson S: *Clinical exercise physiology*, St Louis, 1994, Mosby.)

The Clinical Test of Sensory Interaction on Balance (CTSIB) is a clinical version of the SOT that does not use computerized forceplate technology. The concept of the six conditions remains intact (Figure 22-12). Instead of sway measures, the examiner uses a stopwatch and visual observation. A thick foam pad substitutes for the moving forceplate during conditions four, five, and six. In normal individuals and clients with peripheral vestibular lesions, measures with foam correlate to moving forceplate measures. Originally, a modified Japanese lantern substituted for the moving visual surround in conditions three and six. Studies have not shown that measures using the Japanese lantern correlate with the moving visual surround measures. Most clinicians now perform the modified CTSIB with just four conditions, eyes open and closed on a firm surface and eyes open and closed on the foam surface. The client is asked to stand with feet parallel and arms at sides or hands on hips. At least three and up to five 30-second trials of each condition are performed. The watch is stopped if the client steps, reaches, or falls during the 30 seconds. If the client is very steady for 30 seconds on the first trial of a condition, some clinicians choose not to test the remaining trials in that condition and will give the client a full score for that condition. A maximum score for five trials of each condition is 150 seconds. Individuals with normal movement abilities are able to stand without stepping, reaching, or exhibiting loss of balance for 30 seconds per trial per condition. It is possible. Clients with somatosensory loss from spinal cord injury, diabetes, or amputation have difficulty in this condition. Functional situations in which these clients may be at risk for falls would have both inadequate lighting and compliant or unsteady surfaces (e.g., walking on a gravel driveway or thick carpet in the dark).

Under both conditions three and six, the visual surround is sway referenced (visual cues are available but inaccurate). By comparing sway during these two conditions with sway in the absence of vision (conditions two and five, with eyes closed), determining how well the client can recognize and subsequently suppress inaccurate visual inputs when they conflict with somatosensory and vestibular cues is possible. Some clients with CNS lesions (e.g., head injury, stroke, tumor) may have difficulty with this condition. Clients who cannot recognize and ignore inaccurate visual cues cannot distinguish whether they are moving or the environment is moving. If they perceive that they are moving (away from midline) when they are not, they may often actively generate postural responses to “right” themselves. These responses, invoked to bring the COG to midline, then result in movement away from the midline. The inaccurate perception leads to a self-initiated loss of balance. Functional situations that correlate with this test condition include public transportation, grocery and library aisles, and moving walkways.

The SOT is valid and reliable in the absence of motoric problems, which increase sway for reasons unrelated to sensory reception and perception. Normative data are available.

Figure 22-10 The six Sensory Organization Test conditions. The Sensory Organization Test determines the relative reliance on visual, vestibular, and somatosensory inputs for postural control using computerized dynamic posturography. (From Hasson S: *Clinical exercise physiology*, St Louis, 1994, Mosby.)
normal for sway to increase slightly as the conditions increase in difficulty. The CTSIB may not be a reliable measure in clients with hemiplegia or other conditions that involve motor deficits in, or abnormal response time through, the lower extremities and trunk. The clinician can use the information regarding client response in a variety of environmental conditions to determine intervention management strategies.

Vestibular System Tests

Please refer to the vestibular section for a thorough presentation of vestibular disorders and their management.

Active Stepping

The ability to change the base of support without balance loss then to reestablish COG stability over the new base of support is a balance-dependent skill critical for functional activities. The four square step test is a timed stepping test in a standardized, structured format in forward, backward, and lateral directions (Figure 22-13). A simple plus sign–shaped grid is laid out on the floor using four straight canes, dowel rods, or plastic piping. This creates four quadrants. The client begins standing in the rear-left quadrant, steps forward over the first bar to stand with both feet in the front-left quadrant, steps rightward over the second bar to stand with both feet in the right-front quadrant, steps backward over the third bar to stand with both feet in the right-rear quadrant, steps leftward over the fourth bar to stand with both feet in the left-rear quadrant (starting location), then reverses direction, going back through each quadrant in the same way until standing again with both feet in the rear-left quadrant. The outcome measure is the time it takes the client to perform this task correctly, clearing each bar completely with each foot. This test has been used with older adults, individuals with vestibular disorders, and clients poststroke.

Functional Scales

A comprehensive balance evaluation must include both impairment-based tests of body systems and activity-based functional measures. Functional scales help address the activity limitations. By asking the client to perform functional tasks that demand balance skills, the clinician can determine the presence of activity limitations that will affect the individual’s ability to participate in life, and identify the tasks that the client needs to practice. Three mobility scales and three gait scales focus on postural control; five of these were developed for the elderly population to determine risk of falls. Many clinicians are also using them to assess clients with neurological conditions, although their usefulness with neurological populations is less well-documented. Far fewer standardized tests for high-level balance skills have been developed; some clinicians adapt tests used by athletes, but

**Figure 22-11** Postural sway measures from each of the six Sensory Organization Test conditions are compared, and the ratios are used to identify impairments in the use of sensory inputs for postural control. (From Jacobson GP, Newman CW, Kartush JM: Handbook of balance function testing, St Louis, 1993, Mosby.)
Figure 22-12 ■ The Clinical Test of Sensory Interactions on Balance uses foam and a Japanese lantern to replicate the six sensory conditions. A stopwatch is used to time trials.

Figure 22-13 ■ The floor grid for the timed Four Square Step Test (FSST). Arrows indicate the direction of the steps. (From Dite W, Temple VA: A clinical test of stepping and change of direction to identify multiple falling older adults. Arch Phys Med Rehabil 83:1568, 2002.)

these are often too difficult for many neurologically involved clients.

The Berg Balance Scale consists of 14 tasks that the client is asked to perform. The examiner rates the client on each task by using an ordinal rating scale of 0 to 4, in which 0 is unable to perform and 4 is able to perform without difficulty. This test is highly reliable. It was originally designed for assessing risk of falls in older adults, and cutoff scores for fall risk vary depending on which of several studies is consulted. Use of higher cutoff scores may erroneously identify nonfallers as fallers; use of lower cutoff scores may erroneously identify fallers as nonfallers. The Berg Balance Scale has also been used with clients after stroke.

The original Get-Up-and-Go Test is made up of seven items and subjectively scored on an ordinal rating scale of 1 to 5, in which 1 is normal and 5 is severely abnormal. This test has been modified by making it a timed measure to increase its objectivity and reliability, which is now high. The TUG test eliminates the “standing steady” segment and uses a stopwatch to time the performance. Clients are asked to rise from a chair with arms, walk 3 meters as fast as they safely can, turn, walk back to the chair, and sit down. This test may be performed with an assistive device; however, the use of a device will alter the speed at which the task can be accomplished, and any retesting must be done with the same device to produce comparable results. Originally designed
to assess frailty in older adults, the test is now more commonly used to assess fall risk in this population. Young adults typically perform this task in 5 to 7 seconds, healthy older adults in 7 to 9 seconds (low risk), moderate-risk older adults in 10 to 12 seconds, and high-risk older adults in 13 seconds or more.\textsuperscript{78,79} These cut-off scores are for older adults walking without assistive devices. Improvements in test performance that are not captured by the time score alone should also be documented, for example, if the client can now perform the test without the use of chair arms to stand up, or without an assistive device.

The Tinetti Performance-Oriented Mobility Assessment—Balance subscale (POMA-Balance) is a list of nine items scored on scales of either 0 to 1 or 0 to 2, with the higher numbers reflecting better (more normal) performance.\textsuperscript{80} The score value is specific to the item. The best possible score is 16, with a score of 10 or lower indicating a high risk of falls.\textsuperscript{81} Most balance and mobility scales have been developed to assess risk of falls in older adults. Many share similar items. See Table 22-2 for a summary of scale items.

The Tinetti Performance-Oriented Mobility Assessment—Gait subscale (POMA-Gait) is a list of seven normal aspects of gait that are observed by the examiner as the client walks at a self-selected pace and then at a rapid but safe pace.\textsuperscript{80} Scoring scales are again either 0 to 1 or 0 to 2, and higher numbers indicate better performance. Score values are specific to the item being observed (Table 22-3). The best possible score is a 12; scores of 8 or below indicate a high risk of falls. When combined, the Tinetti POMA balance and gait scales offer a best possible score of 28, with scores of 19 or less indicating a high fall risk.

The original Gait Assessment Rating Scale (GARS) is a list of 16 abnormal aspects of gait observed by the examiner as the client walks at a self-selected pace (see Table 22-3).\textsuperscript{82} These abnormalities are commonly seen in older adults who fall, who are fearful of falling, or both. The items are scored on a scale of 0 to 3, with lower numbers reflecting better (less abnormal) performance. The best possible score is 0. This gait scale provides some relative numerical indication of the quality of gait. A shorter, modified version of this test, the Modified GARS, has been developed. The Modified GARS (GARS-M) includes nine of the original items plus a gait velocity measure. It provides equivalent sensitivity and takes less time to perform.\textsuperscript{83} These two gait scales were developed to assess risk of falls in older adults.

The Dynamic Gait Index (DGI) is a gait test specifically designed to look at postural control during gait.\textsuperscript{12} It includes eight items requiring changes in gait speed, walking with horizontal and vertical head turning, whole-body turns during gait, stepping over and around obstacles, and stair ascent and descent. Items on this test are scored on a 4-point ordinal scale of 0 to 3, with 3 being normal performance and 0 indicating severe impairment. The best possible score on this test is a 24, and scores of less than 19 points have been associated with impairment of gait and fall risk. The presence of head motion and whole-body turns in this test may help identify clients with potential vestibular dysfunction.

### Table 22-2 | Balance and Mobility Scale Items

<table>
<thead>
<tr>
<th>Activity</th>
<th>Berg Balance Scale</th>
<th>Dynamic Gait Index</th>
<th>Timed Up-and-Go Test</th>
<th>Tinetti Balance Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sitting unsupported</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Sitting to standing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Standing to sitting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Transfers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Standing unsupported</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Standing with eyes closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Standing with feet together</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Tandem standing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Standing on one leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Rotating trunk while standing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Retrieving object from floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Turning 360 degrees</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Stool stepping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Reaching forward while standing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Sternal nudge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Walking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Abrupt stop</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Walking then turning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Stepping over obstacle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Stairs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Walking at preferred and varied speeds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Walking with horizontal and vertical head turns</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23. Stepping around obstacles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The reliability of this test is high. A modified and slightly more difficult version of this test, the Functional Gait Assessment (FGA), has been developed specifically for use with patients with vestibular disorders. The best possible score on the FGA is 30 points, and a score of 22 points or below can be used to classify fall risk and predict unexplained falls in community-dwelling older adults. The three gait tests listed previously are distinct from traditional gait tests because they focus on elements of postural control during gait. One very important traditional gait measure that should be included in the assessment of balance and gait in older adults and clients with neurological disorders is gait speed. This measure has been termed “the sixth vital sign” for older adults because of its strong association with level of dependence in activities of daily living (ADLs) and instrumental ADLs (IADLs), probability of hospitalization, risk of falls, eventual discharge location, and ambulation category.

**Combination Test Batteries**

Because no single test can give a complete picture of a client’s balance abilities, individual test items are often combined to form a test battery. Several of the tests described earlier, such as the Berg Balance Scale and the Tinetti POMA, include a combination of multiple items and could be categorized as combination test batteries. Different items on a test may challenge different components of the postural control system to permit a more complete assessment of the client’s balance abilities.

The BESTest is an excellent comprehensive test battery based on the system’s model of postural control (see Figure 22-3). It includes seven categories representing components of postural control: biomechanical constraints; stability limits; anticipatory postural adjustments; automatic postural responses; sensory orientation, and stability during gait. Within each category are individual test items and, in some cases, existing tests. For example, the sensory orientation category contains the individual item “Stand on incline with eyes closed” and the four-condition CTSIB discussed earlier. Although the BESTest takes approximately 30 minutes to administer, the information acquired helps to identify which underlying components of the postural control system are causing the observed balance problems. Armed with this critical information, the clinician can design a customized, individualized intervention program that targets the sources of imbalance in each client.

A shorter version of this test has been developed, the Mini-BESTest (see Figure 22-3). It includes 14 of the original 36 items, has a compressed rating scale, and takes approximately 15 minutes to administer. It does not include any items from the biomechanical constraints category or the stability limits category. This does not mean that these components need not be measured. Biomechanical constraints such as hip and ankle weakness, and constricted limits of stability, seriously negatively affect balance and should be tested in addition to administration of the Mini-BESTest. The compressed rating scale may reduce the ability of this test to reflect a client’s progress over time.

The Fregly-Graybiel Ataxia Test Battery is a more challenging test appropriate for clients with higher-level balance skills. It includes eight test items that the client must perform (Figure 22-14). Standing trials in tandem stance both off and on a rail with eyes open and closed are timed. Timed single-leg stance trials also are performed for each leg. Walking 10 steps with eyes closed is included. Five trials of each task are given. Trials are stopped if the client uncrosses the arms, opens the eyes (during eyes-closed trials), steps (during standing trials), or falls. Trials are judged on a pass/fail basis. This test battery is valid for use with clients who have peripheral vestibular dysfunction. Normative data are available from a normative database compiled primarily of findings in young men. As noted earlier, clients must be at a high level motorically to perform these tasks. This test is a good choice for clients with higher-level abilities because it does provide more demanding balance tasks. Interpretations regarding a client’s use of sensory inputs when motor involvement is also present cannot be made with certainty.

The Fugl-Meyer Sensorimotor Assessment of Balance Performance is a subset of the Fugl-Meyer Physical Performance Battery, which was designed for use with hemiplegic clients (Figure 22-15). Three sitting and four standing balance activities are listed. The items are scored on a 0 to 2 scale, with score values specific to each item. Higher scores indicate better performance; the maximum (best) score is 14. However, a client could achieve this score of 14 and still not have normal balance.

The Dizziness Handicap Inventory (DHI) was developed to identify specific functional, emotional, or physical problems associated with an individual’s reaction to imbalance or
### FREGLY TEST

<table>
<thead>
<tr>
<th>Condition</th>
<th>Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sharpless Romberg, EC (60 sec; feet in tandem)</td>
<td>x</td>
</tr>
<tr>
<td>2. Walk on Rail, EO (5 steps; best 3/5 trails)</td>
<td>x</td>
</tr>
<tr>
<td>3. Stand on Rail, EO (3 trials; 60 sec/trial)</td>
<td></td>
</tr>
<tr>
<td>4. Stand on Rail, EC (3 trials; 60 sec/trial)</td>
<td>x</td>
</tr>
<tr>
<td>5. Stand on Right Leg, on Floor, EC (5 trials; 30 sec/trial)</td>
<td>x</td>
</tr>
<tr>
<td>6. Stand on Left Leg, on Floor, EC (5 trials; 30 sec/trial)</td>
<td>x</td>
</tr>
<tr>
<td>7. Walk on Floor, EC (3 trials; 10 steps each)</td>
<td></td>
</tr>
<tr>
<td>8. Stand sideways on rail [characterize sway]*</td>
<td></td>
</tr>
</tbody>
</table>

*Added by the author to observe the movement strategy used by the individual.
EO, eyes open; EC, eyes closed.

**Figure 22-14** A combination of tasks (Romberg test, one-legged stance test [OLST], walking) and environments (eyes open, eyes closed, rail) are included in the Fregly-Graybiel Ataxia Test Battery. (From Newton R: Review of tests of standing balance abilities. *Brain Inj* 3:335, 1989.)

### FUGL-MEYER

<table>
<thead>
<tr>
<th>Test</th>
<th>Scoring</th>
<th>Maximum Possible Score</th>
<th>Attained Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sit without support</td>
<td>0—Cannot maintain sitting without support</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1—Can sit unsupported less than 5 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2—Can sit longer than 5 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Prolong reaction, non-affected side</td>
<td>0—Does not abduct shoulder or extend elbow</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1—Impaired reaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2—Normal reaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Prolong reaction, affected side</td>
<td>Scoring is the same as for test 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Stand with support</td>
<td>0—Cannot stand</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1—Stands with maximum support</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2—Stands with minimum support for 1 minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Stand without support</td>
<td>0—Cannot stand</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1—Stands less than 1 minute or sways</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2—Stands with good balance more than 1 minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Stand on unaffacted side</td>
<td>0—Cannot be maintained longer than 1-2 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1—Stands balanced 4-9 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2—Stands balanced more than 10 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Stand on affected side</td>
<td>Scoring is the same as for test 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 22-15** The Fugl-Meyer Sensorimotor Assessment of Balance Performance includes both low-level and high-level tasks. (From DiFabio RP, Badke MB: Relationship of sensory organization to balance function in patients with hemiplegia. *Phys Ther* 70:20, 1990.)

Dizziness. The DHI assesses the client's perception of the effects of the balance problem and the client's level of emotional adjustment. It also looks at perceived physical limitations as a consequence of the disorder. Twenty-five items are divided into three subscales in this self-assessment inventory. Included are a nine-item functional scale, a nine-item emotional scale, and a seven-item physical scale. Each item is assigned a value of four points for a "yes," two points for a "sometimes," and zero points for a "no." This inventory is reliable, is easy to administer, and can be used to evaluate treatment outcomes. Changes in scores on the functionally based DHI correlate highly with changes in scores on the impairment-based SOT. The DHI can be given before the initial evaluation to help determine which physical tests should be performed. An astute clinician can see patterns of dysfunction within the reported symptom level. For example, visual motion sensitivity and visual dependency can be indicated from the answers about grocery stores, crowds, riding in a car, or difficulty at night. Imbalance usually is indicated when the client has difficulty walking down a sidewalk and using stairs. Patients with chronic mild head injury often will report many activities as most provoking because of their inability to integrate the sensory systems and poor motor control for balance.
Dual-Task Tests
In everyday life tasks, normal balance is largely unconscious and does not compete for attentional resources. In clients with balance disorders, however, the challenge of maintaining postural control during upright activities and gait is often sufficient to demand the use of attentional resources. The interaction of cognitive demands and postural control demands is examined in dual-task tests that add concurrent cognitive and motor tasks to gait tasks. At the simplest level are the walking while talking (WWT) and stops walking when talking (SWWT) tests.32-35 In these tests the client is asked to walk and, while the client is walking, the clinician asks the client one or more questions and observes if the client must stop walking to answer the question(s). If so, the test result is positive—that is, the client must stop attending to the postural control demands of walking to reallocate attention to the cognitive task. These are gross measures, apt to identify only those with more severe attentional balance problems or to misidentify clients who prefer to chat and rest rather than keep walking. A more formalized dual-task test is the Multiple Tasks Test (MTT), which includes eight items involving gait plus other verbal cognitive and motor tasks such as carrying a tray and avoiding obstacles.96,97 Two dual-task versions of the TUG have been developed. The TUG-Manual involves performing the TUG while carrying a cup nearly full of water. The TUG-Cognitive involves performing the TUG while subtracting backward from a randomly selected number or spelling words backward.98 The Walking and Remembering Test (WART) requires the client to remember a set of numbers that the tester speaks aloud while the client walks as quickly as possible while trying not to step off of a narrow path.99 Once the walk is completed, the client must repeat the numbers in sequence. For all dual-task tests, performance of each single task is measured separately first. Then the dual-task performance is recorded. The difference for each of the two scores (physical and cognitive performance) between undivided attention and divided attention conditions is calculated.

Balance Confidence Tests
Reduced participation in functional activities may occur not only because balance impairments impede participation, but also when clients are anxious about falling. Fear of falling may lead individuals to avoid activities that they remain quite capable of doing.100 In turn, prolonged self-restriction of activity leads to the many negative consequences of being sedentary—decreased ROM, weakness, low endurance, and so on—and thus ironically further impairs balance and increases fall risk.101,102 As this worsening balance and increased risk is perceived by the client, further activity restriction occurs, creating a self-perpetuating downward spiral leading to social isolation, anxiety, and depression.103,104 It is just as important to address poor balance confidence as it is to address poor balance, for without sufficient balance confidence a client will not participate in activities even if balance abilities permit him or her to do so. The client will lose all the gains made in therapy if he or she does not remain active, and he or she will not be active if fearful of falling.

The two most commonly used measures of balance confidence are the Activities-specific Balance Confidence Scale (ABC Scale), and the Falls Efficacy Scale (FES).105,106 Both are questionnaires that are easy to administer. The ABC Scale consists of 16 items that range in difficulty from “walk around the house” to “walk outside on icy sidewalks.” Several of the items inquire about activities in public places, for example, parking lots and escalators. Clients are asked how confident they are that they could do each of the activities without losing their balance or becoming unsteady. Responses are given on a scale from 0 to 100 in increments of 10, with higher numbers indicating higher confidence. More recently a short version, the ABC-6, has been developed. It has six of the original 16 items and takes less time to administer, yet retains good reliability and correlation with balance and fall risk measures.107 The FES consists of 10 activity items that are less difficult than the items on the ABC Scale. Items on the FES include getting in and out of a chair and answering the door or a phone. All of the items refer to activities done in the home. Clients are asked how confident they are that they could do each of the activities without falling. Responses are given on a scale from 1 to 10, with lower numbers indicating higher confidence. The Modified FES (MFES) has 14 activity items and includes two activities done outside the home and three activities done in public spaces. It also takes into account whether or not an assistive device is used.108 Scoring is identical to that of the original FES.

A third measure of fear of falling is the Survey of Activities and Fear of Falling in the Elderly (SAFFE).109 This measurement instrument is more involved than the ABC Scale or MFES; however, it provides additional information specific to activity restriction that is valuable to the clinician. The SAFFE has 11 activity items that are similar in nature to the items on the other two scales, including community activities. This questionnaire asks if the client actually does the activity or not. If he or she does the activity, the questionnaire asks how worried the client is that he or she might fall during the activity, on a scale from 1 to 4. Lower numbers indicate increased worry. If the client does not do the activity, the client is asked whether the reason he or she does not do the activity is fear of falling, with degree of fear scored on the scale from 1 to 4, or whether the client does not do the activity for reasons other than fear, and what those other reasons are. For each item, clients also indicate whether the frequency of doing the activity has increased, decreased, or remained the same. The SAFFE takes longer to administer than the ABC Scale or MFES but provides explicit results about activity restriction not obtained from the other two scales.

The Fear of Falling Avoidance Behavior Questionnaire (FFABQ) is a recently developed instrument with a focus on activity avoidance versus fear.110 It lists 14 different activities, ranging in difficulty from walking and preparing meals to going up and down stairs to engaging in recreational activities such as sports or traveling. Clients rate whether or not they agree with a statement that they avoid a specified activity on a 5-point scale from 0 (completely disagree) to 4 (completely agree). This questionnaire is reliable, with scores that discriminate between previous fallers and nonfallers, and more versus less active individuals. The shift from an emphasis on fear or confidence as in the ABC and FES, to activity avoidance as in the SAFFE and FFABQ is an important and positive one for physical and occupational therapists. As the ICF health and disablement model describes, our goals are to increase activity and participation to achieve an improved quality of life for our clients.
Considerations in the Selection of Balance Tests

To determine the type and level of challenge of the tests to be used during the examination, a thorough subjective history is critical. In describing the symptoms and the situations that cause dizziness or imbalance, the client offers clues to possible deficits and thereby the measures that will help identify them.

Many of the functional scales previously reviewed were designed to determine whether balance is abnormal in elderly clients who have no medical diagnosis, in other words, as screening tools. Clinicians working with clearly diagnosed clients with neurological conditions often do not need such tools to establish that balance skills are abnormal because the deficits are patently obvious. These screening tools can be useful, however, to identify disabilities, establish a baseline, monitor progress, and document outcomes.

Many clinical facilities have their own therapy evaluation forms that include a section on balance. Items and scoring are usually defined by the facility. They are not standardized across sites, as are published scales, and are rarely tested for measurement qualities such as validity and reliability. As rehabilitation professions evolve toward evidence-based practice, nonstandardized tests with unknown measurement quality are no longer acceptable. Clinicians should use standardized, objective, quantifiable, valid tests with high reliability, sensitivity, and specificity whenever possible. Facilities insistent on using their own tests should conduct research to ensure that they are valid, reliable, and responsive to change over time. A functional balance rating scale is important in the evaluation of clients with neurological impairment. To be responsive enough to measure changes in clients who clearly are not (and may never be) clinically normal, scales should have at least five, and perhaps seven, possible relative scores.

In addition, additional tests are necessary to assess the systems that may affect postural control to help identify and measure impairments (e.g., ROM, strength, sensation and sensory organization, motor planning and control). These types of measures should be sensitive, objective, and quantifiable. Unfortunately, some body system components do not have objective, quantifiable clinical measures (e.g., motor planning, coordination). In these cases, clinicians must continue to use subjective rating scales.

Other factors to include when deciding what tests to use are the time required to perform the test, the number of staff members who must be present, and the space and equipment needed. Clinicians must weigh the potential benefits of technological tools (e.g., computerized forceplates, isokinetics, motion analysis, electromyography) against their cost and practicality (i.e., their cost-effectiveness). The test must be suitable for the client’s level of functioning (physical and cognitive). Many head-injured clients, for example, cannot initially participate in traditional forms of testing because of cognitive limitations.

PROBLEM IDENTIFICATION, GOAL SETTING, AND TREATMENT PLANNING

Clinical Decision Making

Treatment of clients with neurological diagnoses is based on the particular set of impairments and activity limitations possessed by each individual. Remediation of balance deficits similarly must be specific to the involved body systems and functional activity losses in each client. Clinicians should generate an overall problem list for each client; if imbalance is a listed problem, then a sublist of balance problems also can be developed (Figure 22-16).

EXAMPLE OF BALANCE PROBLEM LIST

<table>
<thead>
<tr>
<th>General Problem List</th>
<th>Balance Problem List</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Decreased strength (L) side</td>
<td></td>
</tr>
<tr>
<td>2. Decreased ROM (L) shoulder</td>
<td></td>
</tr>
<tr>
<td>3. Decreased endurance</td>
<td></td>
</tr>
<tr>
<td>4. Impaired sensation (L) side</td>
<td></td>
</tr>
<tr>
<td>5. Decreased balance</td>
<td></td>
</tr>
<tr>
<td>6. Increased tone (L) side</td>
<td></td>
</tr>
<tr>
<td>7. Synergistic movement (L) side</td>
<td></td>
</tr>
<tr>
<td>8. Min. assist transfers</td>
<td></td>
</tr>
<tr>
<td>9. Mod. assist ambulation</td>
<td></td>
</tr>
<tr>
<td>a. Decreased weight bearing on left (L) LE</td>
<td></td>
</tr>
<tr>
<td>b. Unable to maintain midline orientation</td>
<td></td>
</tr>
<tr>
<td>c. Excessive sway with eyes closed</td>
<td></td>
</tr>
<tr>
<td>d. Unable to stand on (L) LE</td>
<td></td>
</tr>
<tr>
<td>e. Decreased limits of stability to 45/100%</td>
<td></td>
</tr>
<tr>
<td>f. Unable to shift to (L) side</td>
<td></td>
</tr>
<tr>
<td>g. Unable to establish stable base of support</td>
<td></td>
</tr>
<tr>
<td>h. Unable to stand on unstable surface</td>
<td></td>
</tr>
<tr>
<td>i. Unable to perform hip strategy</td>
<td></td>
</tr>
</tbody>
</table>

Figure 22-16  An example of a balance-specific problem list (as a subset of a general problem list), which should be developed to guide balance rehabilitation treatments.
To direct and establish priorities for treatment, clinicians must review the problem list and ask themselves the following questions (Figure 22-17): Which impairments are temporary and can be remediated? How much improvement can be expected? How soon will it occur? Which impairments are permanent or progressive and must be compensated for? What other body systems can be counted on to substitute? What external compensations may be needed?

For some clients with neurological impairments, knowing whether a problem is permanent or temporary is not possible, as in recovery from a stroke or head injury. In others with progressive diseases such as Parkinson disease or MS, the rate of decline is unknown and abilities may fluctuate. In these cases the clinician should consider the following issues: Would a consultation provide the required information? If so, referral is appropriate. Do any contraindications to treatment exist? What are the risks and benefits of providing versus withholding treatment? Is some amount of functional improvement possible? If no contraindications are present, the benefits outweigh the risks, and functional improvement is expected, then a trial of treatment may be given, even if knowing for certain whether the problem(s) will respond to the treatment is not possible. In these cases especially, a baseline must be established against which to measure any change. Change for the worse or no change after a reasonable trial period indicates that treatment should be altered or discontinued.

### Using the Systems Model to Identify Postural Control Impairments

The systems approach is useful to develop a balance problem list because it can be applied to different diagnoses equally well and allows deficits in multiple systems to be recognized. Table 22-4 illustrates several examples of ways this framework is used to identify balance deficits in clients with different neurological diagnoses.

For each client, problems affecting postural control should be described in objective, measurable terms whenever possible. For example, the term “impaired vision” is too vague; “four-line drop on eye chart” is more specific. “Poor use of visual inputs for balance control” is an interpretation; the objective result could be stated “Loss of balance after less than 15 seconds on 5/5 trials of standing on...”

### TABLE 22-4 EXAMPLES OF MEDICAL DIAGNOSES AND RELATED IMPAIRMENTS AFFECTING BALANCE

<table>
<thead>
<tr>
<th>IMPAIRMENTS FROM SYSTEMS MODEL</th>
<th>CLIENT WITH DIABETIC STROKE</th>
<th>CLIENT WITH PARKINSON DISEASE</th>
<th>CLIENT WITH INCOMPLETE PARAPLEGIA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PERIPHERAL SENSORY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vision</td>
<td>Retinopathy</td>
<td>Cataracts</td>
<td></td>
</tr>
<tr>
<td>Vestibular</td>
<td></td>
<td>Hair cell loss</td>
<td></td>
</tr>
<tr>
<td>Somatosensory</td>
<td>Peripheral neuropathy</td>
<td>Slowed transmission time</td>
<td>Complete loss</td>
</tr>
<tr>
<td><strong>CENTRAL SENSORY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vision</td>
<td>Hemianopia</td>
<td>Vision dominant</td>
<td>Needs superior use to compensate</td>
</tr>
<tr>
<td>Vestibular</td>
<td>Failure to use inputs</td>
<td>Failure to use inputs</td>
<td>Needs superior use to compensate</td>
</tr>
<tr>
<td>Somatosensory</td>
<td>Failure to use inputs</td>
<td>Ankle dominant</td>
<td>Hip dominant</td>
</tr>
<tr>
<td>Strategy selection</td>
<td>Step dominant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perception of position in space</td>
<td>Midline shift with left neglect</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CENTRAL MOTOR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timing</td>
<td>Increased reaction time</td>
<td>Bradykinesia</td>
<td></td>
</tr>
<tr>
<td>Sequencing</td>
<td>Disordered</td>
<td>Co-contraction</td>
<td></td>
</tr>
<tr>
<td>Force modulation</td>
<td>Spasticity</td>
<td>R rigidity</td>
<td></td>
</tr>
<tr>
<td>Error correction</td>
<td>Use right side only</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PERIPHERAL MOTOR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range of motion</td>
<td>Knee hyperextension</td>
<td>Bilateral ankle plantar flexor contractures</td>
<td>Hip flexion contractures</td>
</tr>
<tr>
<td>Strength</td>
<td>Decreased left side</td>
<td>Decreased bilateral extremities and trunk</td>
<td>Severe weakness bilateral lower extremities and trunk</td>
</tr>
<tr>
<td>Endurance</td>
<td>Severely impaired</td>
<td>Moderately impaired</td>
<td>Mildly impaired</td>
</tr>
</tbody>
</table>
foam, eyes open.” Documenting problems in this manner makes goal writing (and subsequent treatment planning) much easier.

**Writing Goals on the Basis of Body Structure and Function Impairments and Activity Limitations**

Goals also should be stated in objective and measurable terms so that their achievement can be judged. “Improved balance” is open to any interpretation, whereas “able to stand on right leg for 30 seconds on 3/3 trials” and “walks tandem entire length of balance beam without misstep 7/10 times” are measurable goals. These types of goals may be helpful to the clinician who understands the link between impairments and function, but they may seem nonfunctional (and therefore unnecessary) to others who read them (e.g., case managers, third-party payers). From their standpoint, incorporating the functional task that will be positively affected by its achievement into the impairment goal is beneficial; for example, “able to stand on right leg for 10 seconds at a time so that stairs can be ascended and descended step-over-step without railing,” or “walks tandem on balance beam to demonstrate ability to avoid falls using hip strategy.” By describing the specific system problem (e.g., power, range, balance strategies) as it relates to function in the treatment objectives, clinicians force themselves to focus on functional outcomes and illustrate for others why these goals are meaningful. The need for and validity of the treatment are then more likely to be clearly perceived. At times, goal documentation requirements may specify that the goals be purely functional in nature. Writing goals without impairment components may meet the needs of the reviewer, but they will not help to direct clinical interventions to the specific components that need to be addressed in each individual client. Documentation must meet reviewer requirements, but for one’s own benefit, writing a separate set of goals with the dual impairment-function component will assist the clinician with planning and prioritizing treatment.

If a problem cannot be alleviated and requires compensation, the goal(s) should reflect this as well. For example, a client with diabetes has progressive peripheral neuropathy with somatosensory loss and ineffective ankle strategy. If the client’s visual and vestibular sensory systems and proximal strength are relatively intact, however, then the goals might mention improved use of visual cues and successful substitution of hip and stepping strategies. Educational and environmental modification goals for safety also are appropriate in these situations.

**Developing a Treatment Plan**

Once the goals have been listed and priorities established, the treatment plan is developed. The most effective and efficient treatments focus first on those problems with the greatest impact on function and address more than one problem at a time. Training balance on an unstable surface contributes to the use of visual and vestibular inputs as well as to the use of hip strategy, increased lower-extremity strength, and increased motor control (skill) on that type of surface. Training gait on an inclined treadmill with eyes closed or head movement increases the use of somatosensory and vestibular inputs, endurance, postural control, ROM, and lower-extremity strength.

Creative clinicians develop comprehensive treatment plans with this type of multiple-problem approach to maximize the time available with clients.

The clinician must thoughtfully choose environments and tasks that together stimulate and challenge the appropriate postural control systems. To stimulate one sensory system, the other systems must be placed at a disadvantage to force reliance on the targeted system. The environment is then structured to put the other systems at a disadvantage (e.g., training with eyes closed or in the dark puts vision at a disadvantage and forces the use of somatosensory and vestibular inputs). If one side or limb is significantly more affected, such as in hemiplegia, then the other side must be disadvantaged to force reliance on the targeted side. Tasks are then selected to disadvantage the less affected side. For example, placing the less affected leg on a step or small ball makes it more difficult to use for balance and forces the transference of weight to the more affected leg. To achieve optimal function, however, all systems and all sides must be capable of working together, so training to improve balance impairments must be incorporated and interspersed with training functional tasks. For carryover of improvements into real-life situations, training tasks should be varied enough to promote motor problem solving on the part of the client. For example, sitting balance and transfers should be taught using stable and unstable surfaces, with different heights and firmnesses, with and without armrests and back supports, and using both right and left sides. This technique may improve the client’s abilities to perform safe sitting and transfers in new situations not previously practiced in therapy.

Tables 22-5 through 22-7 illustrate the process of test choice, problem identification based on test results, goal setting based on impairments and disabilities, and treatment planning based on goals in three different types of clients. Note that only selected tests were performed for each client. Goals were directly related to the problems that were identified by the tests, and treatment plans followed directly from the goals.

**BALANCE RETRAINING TECHNIQUES**

**Motor Learning Concepts**

Although covering the principles of motor learning is not within the scope of this chapter (refer to Chapter 4), the discussion of balance retraining methods is not possible without some consideration of several motor learning concepts that must be incorporated into treatment. The clinician must remember that successful treatments address the interaction of the individual, the task, and the environment (Figure 22-18).  

**Individual**

Therapists should know their clients’ impairments: sensory and motor, peripheral, and central. Whenever possible, therapists should know which impairments can be rehabilitated and which require compensation or substitution. Because of the nature of neurological insult, this includes an awareness of cognitive and perceptual impairments that may affect the ability to relearn old skills or develop new ones. Optimal learning of skilled movement requires that the client have (1) knowledge of self (abilities and limitations), (2) knowledge of the environment (opportunities and risks),
(3) knowledge of the task (critical components), (4) the ability to use those knowledge sets to solve motor problems, and (5) the ability to modify and adapt movements as the task and environment change. To the extent that a client is missing these characteristics, the clinician should attempt to support his or her development or even supply them until they are present. Different types of clients vary with regard to which characteristics are likely to be missing. For example, a cognitively impaired, head-injured client may lack awareness of self and environment, even though his or her physical abilities make modifying and adapting movements possible. Conversely, a quadriplegic client may be aware of his or her limitations, the environment, and the task demands but may initially have limited experience to know how to solve a motor problem and limited physical ability to modify movements.

The clinician must also ask what motor learning stage the client is in for different tasks. Skill acquisition is the first stage. The objective is for the client to “get the idea of the movement” to begin to acquire the skill. In this stage, errors are frequent and performance is inefficient and inconsistent. Within the nervous system only temporary changes are occurring. Skill refinement is the second stage. The goal is for the client to improve the performance, reduce the number and size of the errors, and increase the consistency and efficiency of the movements. Skill retention is the final stage. The ability to perform the movements and achieve the functional goal has been accomplished, and the new objective is to retain the skill over time and transfer the skill to different settings. Retention and transfer are the hallmarks of true learning, in which some relatively permanent changes have occurred within the nervous system. A client may have attained the skill retention phase for sitting balance tasks, be in the skill refinement stage for standing balance tasks, and be in the skill acquisition stage for locomotor balance tasks.

Therapists use practice and feedback to teach motor skills. Repetition is necessary to develop skill; feedback is necessary to detect and correct errors. During skill acquisition, frequent repetition of a movement or task and frequent feedback are beneficial to help the client begin to be able to...
TABLE 22-6 □ EXAMPLE OF HOW TREATMENT PLANNING FLOWS FROM TEST RESULTS IN AN ELDERLY CLIENT WITH FREQUENT FALLS

<table>
<thead>
<tr>
<th>TEST</th>
<th>PROBLEMS IDENTIFIED</th>
<th>GOALS SET</th>
<th>TREATMENT PLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral sensory</td>
<td>Mildly decreased vibration sense</td>
<td>Compensate for permanent sensory loss</td>
<td>Educate about safe surfaces and lighting</td>
</tr>
<tr>
<td>Sot</td>
<td>Absent use of vestibular inputs 0/100</td>
<td>Increase use of vestibular inputs to 30/100</td>
<td>Somatosensory and vestibular stimulation*</td>
</tr>
<tr>
<td>Somatosensory</td>
<td>Decreased use of somatosensory inputs 60/100</td>
<td>Increase use of somatosensory inputs to 75/100</td>
<td></td>
</tr>
<tr>
<td>Vision</td>
<td>Acuity, cataracts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static postural sway</td>
<td>Excessive sway—2 standard deviations outside normal range for age</td>
<td>Standing sway within normal limits for age</td>
<td>COG control training</td>
</tr>
<tr>
<td>Nudge or push test</td>
<td>No use of ankle or hip strategy</td>
<td>Survives 5/10 pushes with hip strategy</td>
<td>Hip strategy exercises*</td>
</tr>
<tr>
<td>LOS</td>
<td>No ankle strategy—uses hip strategy</td>
<td>Uses ankle strategy to reach 40% LOS anterior and posterior</td>
<td>COG control training</td>
</tr>
<tr>
<td>ROM</td>
<td>Neck extension 0-10 degrees</td>
<td>Spinal extension neck 0-20 degrees</td>
<td>ROM exercises*</td>
</tr>
<tr>
<td>Strength</td>
<td>Hip extension 0-5 degrees</td>
<td>Lumbar extension 0-20 degrees</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hip abduction 3+/5, extension 3/5</td>
<td>Hip extension 0-10 degrees</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knee extension 4+/5, flexion 4/5</td>
<td>(B) Hip abduction and extension to greater than 4/5</td>
<td>Progressive resistive exercises, including bicycle*</td>
</tr>
<tr>
<td></td>
<td>Ankle dorsiflexion 3−/5</td>
<td>(B) Ankle dorsiflexion and plantarflexion to 4+/−/5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ankle plantarflexion 2/5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gait (GARS)</td>
<td>Score 35/48</td>
<td>GARS scales 25/48</td>
<td>Gait training*</td>
</tr>
<tr>
<td></td>
<td>Deviations</td>
<td>(I) Ambulation with walker in home, community</td>
<td>1—starts, stops, turns</td>
</tr>
<tr>
<td></td>
<td>Forward flexed trunk</td>
<td></td>
<td>2—treadmill</td>
</tr>
<tr>
<td></td>
<td>Double limb stance prolonged bilaterally</td>
<td></td>
<td>3—uneven surfaces, curbs, stairs, carpet, outdoors</td>
</tr>
<tr>
<td></td>
<td>Short step length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endurance</td>
<td>Fatigue after ambulating 60 ft</td>
<td>Ambulates more than 200 ft without stopping</td>
<td>Gait training as earlier</td>
</tr>
<tr>
<td>Tinetti balance</td>
<td>6/16 score</td>
<td>Gait training as earlier</td>
<td></td>
</tr>
<tr>
<td>scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinetti gait scale</td>
<td>5/12 score</td>
<td>Tinetti gait score 8/12</td>
<td>Gait training as earlier</td>
</tr>
<tr>
<td></td>
<td>Falls and catches self</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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LOS, limit of stability; (B), bilateral; COG, center of gravity; GARS, Gait Assessment Rating Scale; (I), independent; (L), left; (R), right; ROM, range of motion; SOT, Sensory Organization Test.
*Also included in home exercise program.

perform the desired movements and tasks. As soon as the client progresses to the skill refinement stage (the clinician observes reduced errors and less variable performance), however, then practice should be varied and feedback briefly delayed. For example, the task of standing and reaching to one side to take an object from the therapist might initially be repeated to the same side and at the same height several times. Then the therapist should begin to vary the task demands gradually: reach farther or faster; take different objects of various weights, shapes, and sizes; and take the object from higher and lower heights and alternately reach to right and left sides. This variation introduces a problem-solving demand for the client: modifications in timing, force, and sequencing are now necessary. Feedback, which is especially helpful for those with sensory reception or perception problems, initially may contain information to assist the client in detecting errors about the goal achievement (knowledge of results, such as “you did
not lean far enough to reach this last time”) or about a movement error (knowledge of performance, “you did not straighten your knee enough last time”). Early feedback also may contain cues about what to do better next time, such as “straighten your knee before you shift weight onto that leg.” If feedback is always provided by an external source, such as the therapist, a mirror, or a computer monitor, then the client is not given the opportunity to develop internal error detection and error correction mechanisms and will not be as likely to retain or transfer the skill. By delaying the feedback and asking the client to estimate or describe her or his own errors, and afterward providing the feedback, the therapist allows the client to compare her or his own developing internal frame of reference with the correct external frame of reference. By asking clients to suggest what might be done to correct the errors, the therapist shifts the error correction process from the external source to the clients, supporting motor problem-solving processes. As clients progress to the skill retention level, variations should increase (including task and environmental demands) and feedback delays should be longer. The clinician must develop a sense of how to use practice variation and feedback

<table>
<thead>
<tr>
<th>TEST</th>
<th>PROBLEMS IDENTIFIED</th>
<th>GOALS SET</th>
<th>TREATMENT PLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral somatosensory</td>
<td></td>
<td>None</td>
<td>Vestibular stimulation with forced use and head movements</td>
</tr>
<tr>
<td>SOT</td>
<td>Average overall stability 47/100</td>
<td>Average stability 60/100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Absent use of vestibular inputs 0/100</td>
<td>Use of vestibular inputs 15/100</td>
<td></td>
</tr>
<tr>
<td>Postural sway</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional reach</td>
<td>Forward lean restricted to 5 inches</td>
<td>Able to reach forward 8 inches</td>
<td></td>
</tr>
<tr>
<td>Static balance</td>
<td>Weight shift asymmetry to left in</td>
<td>Forward LOS to 50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>static standing and medial or lateral sway, 25% LOS to left of midline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limit of stability</td>
<td>Forward weight shift restricted to 25% LOS</td>
<td>Right LOS to 50%</td>
<td></td>
</tr>
<tr>
<td>Rhythmic weight shift</td>
<td>Extraneous sway off desired path</td>
<td>Extraneous sway scores by 50%</td>
<td></td>
</tr>
<tr>
<td>OLST</td>
<td>Unable on right leg, 30 seconds on left leg</td>
<td>Stands on right leg, 10 seconds</td>
<td>COG control training</td>
</tr>
<tr>
<td>Nudge, push (motor strategy selection)</td>
<td>Switch from ankle to hip strategy noted but unable to withstand perturbation</td>
<td>Able to stand upright after mild perturbations 5/10 times</td>
<td>Hip and stepping strategy training</td>
</tr>
<tr>
<td>Range of motion</td>
<td>None</td>
<td>Able to “catch” self by stepping or reaching 5/10 times</td>
<td></td>
</tr>
<tr>
<td>Strength: right leg</td>
<td>4/5 Knee extension</td>
<td>RLE strength</td>
<td>Progressive resistive exercises</td>
</tr>
<tr>
<td></td>
<td>3/5 Knee flexion</td>
<td>5/5 Knee</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2/5 Ankle dorsiflexion</td>
<td>4/5 Ankle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3/5 Ankle plantarflexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endurance</td>
<td>Standing tolerance less than 10 minutes</td>
<td>Able to stand unaided for 15 minutes</td>
<td>Standing tolerance tasks</td>
</tr>
<tr>
<td>Gait</td>
<td>Step length—RLE</td>
<td>Symmetrical step height and length 5/10 times</td>
<td>Gait training on treadmill</td>
</tr>
<tr>
<td></td>
<td>Step height—RLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heel strike—RLE</td>
<td>Heel strike RLE 5/10 times</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toe-off—RLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tinetti Gait Subscale</td>
<td>Unable to turn, reach, or bend without loss of balance</td>
<td>8/12 score</td>
<td>Gait training on uneven surfaces, with head movements, with low lighting</td>
</tr>
<tr>
<td>Falls</td>
<td>8/12 score</td>
<td>No falls</td>
<td></td>
</tr>
<tr>
<td>Uneven surfaces</td>
<td>Gait independent without cane in household; with cane in community</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low lighting</td>
<td>Safety education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head turning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No community ambulation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requires cane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requires supervision for household ambulation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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COG, Center of gravity; LOS, limit of stability; OLST, one-legged stance test; RLE, right lower extremity; SOT, Sensory Organization Test.

Patient profile: 69-year-old woman
Diagnosis: Left cerebrovascular accident with right hemiparesis
Course of examination and treatment: Acute rehabilitation → home health → outpatient rehabilitation
delay therapeutically to progress clients through the stages of motor learning. Too much variation and too little feedback early on impede skill acquisition; insufficient variation and excessive feedback later on hamper skill retention and transfer.

**Task**

Functional rating scales performed as a part of the evaluation yield information about what tasks, or functional activities, are limited by the postural control impairments. Bed mobility, sitting, sitting to standing, transfers, standing, walking, working, and sports participation may be affected. Repeating the problematic tasks over and over is one approach; however, analyzing the problematic tasks to determine what postural control demands are placed on the client when undertaking those tasks is far more productive for the clinician. Does a task demand predominantly stability? Mobility? Both? For example, standing to take a photograph demands the ability to hold still, standing to move laundry from the washer to the dryer requires weight shifting, and standing to don a pair of pantyhose calls for both steadiness and movement. All three are standing tasks, but each places different postural control demands on the client. By using task analysis, the therapist may consciously select or design tasks to place specific demands on the client such that the postural control systems that need improvement will be challenged to respond.

Analysis of mobility tasks includes attention to timing, force, and duration of movements. Consider the different timing demands for weight shifting and reaching to catch an item falling from a shelf, take a hot casserole out of the oven, or open a door. Compare the different amounts of force necessary to pick up a heavy suitcase, pick up a baby from a crib, or replace a ceiling light bulb. The duration of a balance demand may be brief, as in recovering from a trip, or extended, as in walking across an icy parking lot. Clinicians should choose tasks that vary these parameters to prepare clients for activities with various mobility demands. Activities that incorporate changing head positions will further challenge the individual with vestibular insufficiency.

Therapists also need to consider whether the elements of the task are predictable or unpredictable. In other words, will the postural control demand be a voluntary movement (e.g., sweeping the porch), an automatic postural response (e.g., missing the last step on a flight of stairs), or an anticipatory postural adjustment (e.g., preceding a lift)? Clients need to learn to respond in all three conditions, which are often combined. For instance, lifting is a voluntary movement. Predicting the load to be lifted leads to anticipatory postural preparation. Counteracting the destabilizing force of a greater-than-predicted load requires an automatic postural response. If, during therapy, the clinician says “don’t let me push you” before nudging the client, the demand is for anticipatory postural adjustment. If the disturbance is provided without warning, the demand calls for APRs. If the clinician requests a lean to the right, that is a voluntary postural adjustment. Activities that demand all three types of balance control, either one at a time or in combination, should be included in balance retraining programs.

**Environment**

Just as tasks can be purposefully selected to promote postural control responses, environmental conditions also must be included in the design of the therapy plan to stimulate the necessary systems. Gravity cannot be manipulated by the clinician, but the client needs to learn to counteract it at different speeds and from different positions, among other things. Familiarity with how gravity can aid movement, as in walking, is also important. The therapist can vary the surface conditions. They may be stable, even, and predictable (hospital hallway, sidewalk), unstable (boat, subway, gravel driveway), uneven (grass, curbs, stairs), or compliant (beach, padded carpeting). Visual conditions also may be manipulated. Visual cues may be available and accurate (daylight, fluorescent lighting), unavailable (darkness or poor lighting, or lack of environmental cues such as a busy carpet pattern on a stairway), unstable (moving crowd, public transportation), used for purposes other than balance (fixation on a ball in tennis), or dependent on head movements. Clinicians should help prepare their clients to function in the real world by training them to maintain balance under different combinations of surface and visual conditions. This includes situations in which cues from the environment agree—that is, visual, somatosensory, and vestibular inputs are all sending the same message, so to speak—as well as in sensory conflict environments, where cues from one system may disagree with (not match) cues from the other sensory systems. Functional situations in which sensory conflicts may exist include elevators, escalators, people movers, airplanes, and subways. An emphasis on being able to adapt to changes in environmental conditions rapidly and effectively is important.

**Intervention**

Successful intervention for the individual with a balance disorder depends on the ability of the clinician to identify the components of the problem. The therapist must create a program that addresses several components at a time, not just for efficiency, but because these systems should be able to function together to perform functional activities in real-world environments. Treatment is oriented toward multiple impairments, with tasks and environments selected to best correct involved or facilitate compensatory systems.

The intervention must be matched to the level and combination of body system impairments. For example, tasks related to the different functions of the sensory systems should be identified and not treated as a single body system...
problem. The clinician should have a good idea of the level of stimulus during each exercise program so that the facilitation is as accurate as possible. Progression of the program follows the changes seen from one intervention to the next to promote carryover and retention of learning. The exercise progression integrates activities that reflect those changes. This usually involves more complex movement skills in a greater range of gradually more challenging environments.

### Sensory Systems

In general, the less sensory information available, the more difficult the task of balancing. A treatment progression might therefore start with full sensory inputs (vision, somatosensory, and vestibular) available in the environment and perhaps augmented feedback if intrinsic sensory channels are deficient, as with somatosensory loss or a vestibular disorder. Challenge is added by manipulating either visual or somatosensory inputs, so that equilibrium must be maintained by using only two of three senses (vision and vestibular or somatosensory and vestibular). If both vision and somatosensory inputs are manipulated, then only the vestibular inputs are a reliable source of sensory information and balance is accomplished with only one of three senses.

Most patients with permanent or progressive vestibular or somatosensory losses naturally compensate and become visually dependent. In cases in which improving the use of somatosensory or vestibular inputs is necessary, the training of vision for stability can be counterproductive, teaching compensation versus improvement of normal function. On the other hand, visual retraining is entirely appropriate for the client with severely compromised somatosensation that cannot be changed, as is common in persons with diabetes.

To stimulate the use of visual inputs, environments are designed to disadvantage somatosensation while providing reliable visual cues (stable visual field with landmarks). Somatosensation cannot be removed as can vision, but it can be destabilized by having the client sit or stand on unstable surfaces (rocker board, biomechanical ankle platform system [BAPS] board, randomly moving platforms) or confused by having the client sit or stand on compliant surfaces that give way to pressure, such as foam, “space boots,” or responsively moving platforms.

To stimulate the use of somatosensory inputs, environments are designed to disadvantage vision while providing reliable somatosensory inputs (stable surfaces, level or inclined). Having the client close the eyes or practice in low lighting or darkness removes or decreases visual inputs. For clients with an overreliance on visual input for balance, the somatosensory system needs to be facilitated while the visual system is disrupted. This can be accomplished by having the client sit or stand on a stable surface while performing quick head turns. For the client with self-limited head movement, the intervention may begin with head movement during quiet standing and progress to head movements during weight shifts and then walking. Eyes-closed standing and weight shifting also increase the use of somatosensation for balance. Optokinetic stimuli in the visual surround also stimulate use of somatosensory inputs.

To stimulate the use of vestibular inputs for adaptation of the CNS, environments are designed to disadvantage both vision and somatosensation while providing reliable vestibular cues (detectable head position). Practicing on unstable or compliant surfaces, with vision either absent (eyes closed), destabilized (eye movements or head movements), or confused (e.g., optokinetic stimulation) provides challenging combinations. Adding neck extension and rotation to place the vestibular organs at a disadvantaged angle can increase difficulty. Gaze stabilization with head turns while standing on an uneven surface or while walking creates a higher-level challenge. Quick movements of the head, head tilts, or forward bending trigger vestibular signals to add input to the system. Combining these types of activities can create progressively more complex challenges. Standing or weight shifting on foam with eyes closed, and head and eye movement while walking all require vestibular input for successful performance.

Additional vestibular challenge can be added by including activities that require quick changes of position in a superior or inferior direction, such as a lunge or going up and down stairs. Other exercises involving up-and-down body movements, such as sitting to standing, seated bouncing on a Swiss ball, and standing bouncing on a mini-trampoline, all with eyes closed to eliminate use of vision for stability, increase the demand on the vestibular system. To train the client who is overreliant on vision to improve the use of vestibular inputs versus vision, activities such as watching a ball being tossed from hand to hand while walking, walking backward, or walking with eye movements can be used. Reading while walking requires the use of vision for reading so that it cannot be used for postural orientation, forcing the other sensory sources to be used for orientation.

### Multisensory and Motor Control Dysfunction

Older clients often have dysfunction in all three sensory systems—that is, a multisensory balance disorder. Disease-related disruptions of the somatosensory or visual system (e.g., a peripheral neuropathy or cataracts) are combined with age-related declines in the vestibular system. In some cases therapy aimed at increasing vestibular function can have a significant impact on postural stability. If sensory loss is permanent or progressive, safe function may require the use of an assistive device. Choosing an assistive device for these clients can be a challenge. An individual with cerebellar or visual-perceptual problems may have more difficulty using an assistive device, and thus it may be contraindicated. For these clients, careful assessment of safety and gait both with and without the device is demanded. A single cane often does not allow for compensation for changes in direction of an impending fall, and a standard aluminum walker does not provide support when changing directions because it must be lifted. The ideal walker has four rotating wheels and thus the ability to change direction without being lifted. This device greatly increases stability, and the client usually describes a significant increase in confidence. Of course, the use of a walker also limits normal use of the upper extremities and trunk during gait and restricts the types of environments that can be negotiated. Making sure the client stands erect in walking versus leaning forward into a permanent flexed position is important in order to retain and/or improve existing postural function.

Many clients with neurological conditions have temporary difficulty with head control early in their recovery, and others have chronic head control problems. Their ability to orient the vestibular organs, eyes, and neck proprioceptors...
properly is impaired, which negatively affects the ability to perceive internal and environmental cues that could assist in balance maintenance. Thus, developing head control is very important. (Refer to Chapter 9 for examples of how to improve head control.) Clients with spasticity or contractures of the ankles and feet who cannot place their feet in full contact with the floor are at a biomechanical disadvantage and also have difficulty receiving somatosensory inputs that could support postural control processes. The more accurate and reliable sensory information available, the greater the chances that the sensoriperceptual processes that contribute to balance can fulfill their role. Treatment progressions should include attention to increasing the client’s ability to receive and process sensory information pertinent to balance control through oculomotor, head, and peripheral limb positioning and movement.

**Control of the Center of Gravity**

Effective control of the COG depends on accurate awareness of body position and motion in space and the relation between body parts (perception) as well as biomechanical and musculoskeletal systems (execution). Trunk and head control abilities are primary. For clients with paralysis or degenerative disease that limits the ability of arms and legs to assist with postural stability, head and trunk control may be the dominant means of balance. Both the head and neck and the trunk need to be able to achieve and hold a midline position, rotate around this midline axis, and move away from and return to the midline without loss of balance. The term *midline* here refers not to a line between right and left sides but to a point at which the right and left and forward and backward components are centered in all planes—medial-lateral, anterior-posterior, rotary, and side bending (shortening and elongation on either side). Midline problems can certainly be caused by body system problems such as weakness, pain, or sensory deficits but can also be caused by perceptual problems that have nothing to do with balance deficits but do cause balance problems.

**Sitting Balance.** In sitting the pelvis and posterior thighs form the primary base of support, with additional stability provided by the feet in contact with the floor. The axis of anteroposterior movement rotates around the greater trochanter, and forward and backward leans are achieved through pelvic and trunk movement. Anterior pelvic tilt with upper trunk extension allows forward reaching and begins the sitting-to-standing transition. Lateral weight shifts with trunk elongation precede right and left reaching and scooting. Lateral weight shifts with trunk rotation permit cross-midline reaching and begin the sitting-to-supine progression. The use of arms to prop in sitting is an extension of the base of support.

**Standing Balance.** In standing, the feet form the base of support. The axis of anteroposterior movement rotates around the greater trochanter, and forward and backward leans are achieved through pelvic and trunk movement. Mediolateral movement occurs with weight shifts from foot to foot. Weight shifts move the COG through space for reaching and lifting tasks as well as in preparation for stepping. Ankle strategy is most effective for forward and backward movement of the COG through the limits of stability on a stable surface. As the COG nears the sway boundary, hip strategy works to restrict its travel. If this fails, stepping or reaching strategies are used to reestablish a new base of support.

**Balance during Gait.** During gait, the COG follows a sinusoidal path as forward progression of the body mass combines with alternating lateral weight shifts to the stance foot (Figure 22-19). Each step creates a new base of support. Assistive devices such as canes, walkers, and crutches extend the base of support and thus reduce the demands on the intrinsic balance control system. In sitting, standing, and walking, control of the COG involves the ability to establish a stable base of support and transfer weight over it. Treatment progressions for COG control then involve training to establish, maintain, and reduce the base of support and to

![Figure 22-19](image-url)
produce automatic, anticipatory, and voluntary postural responses to restrict or produce weight shifts.

Early treatment progression for COG control may include “neurodevelopmental sequence activities” (e.g., prone on elbows, all fours, kneeling, right or left side sitting, half-kneeling), not for the purpose of “reflex development” in the traditional sense but because the task demands are to balance with progressively less surface contact (i.e., shrinking the base of support). Additional benefits include greater control, coordination, and generation of power of the neck, trunk, and axial muscles. It also is useful for simultaneously addressing impairments such as lower-extremity extensor tone, trunk weakness and asymmetries, and head and neck extensor weakness. Functionally, bed mobility and floor-to-stand transfers are related to these progressive position exercises and should be practiced concurrently in low- and high-level clients, respectively.

Sitting balance can be progressed by (1) removing upper-extremity support (hands on firm surface to moveable surface [e.g., ball, bolster, rolling stool], one hand free and both hands free); (2) making the seating surface less stable (mat to bed to rocker board to Swiss ball); and (3) removing the use of one foot by crossing the leg or of both feet by raising the height of the seat so they do not touch the floor. Tasks might include multidirectional weight shifts with the hands in contact with a bolster or ball that is pushed or pulled to and fro, reaching or passing objects, performing upper body tasks (grooming, dressing), managing socks and shoes and so forth.

Sitting to Standing and Transfer Balance. Transitional movements such as sitting to standing and transfers involve large COG excursions over a stable base of support. For sitting to standing, the base of support must change from the seat to the feet. The feet begin to accept the weight first by bringing the lights down low, or wearing sunglasses may decrease automatic, anticipatory, and voluntary postural responses to restrict or produce weight shifts. Challenge is added by increasing the distance traveled away from midline, moving toward restricted regions of the limits of stability, altering speed of sway, adding combined upper-extremity activities (e.g., dribbling a basketball, reaching), or adding resistance (manual, flexible bands). Narrowing the base of support (Romberg, tandem, single leg) makes control of the COG more demanding. Placing the feet in a diagonal stride position is more desirable for pregait weight shifting than is symmetrical double stance. Attention should be given to the stance (loading) leg with regard to pelvic protraction, hip and knee extension, and ankle dorsiflexion, with the tibia traveling forward over the foot. Focus on the swing (unloading) leg should include pelvic drop with knee flexion as the heel comes up and pressure through the ball of the foot to the toes to load the opposite leg maximally. Standing balance exercises can be made more difficult by training on a less stable surface (carpet, foam, rocker board, BAPS board) and by adding combined head and eye movements or closing the eyes. The goals for dynamic sitting and standing balance exercises are to increase the size and symmetry of the limits of stability and improve the ability to transfer weight to different body segments with control at different speeds and with varied amounts of force. To facilitate somatosensory and vestibular integration, these activities can be performed with decreased or distorted visual cues. Closing the eyes, turning the head quickly, turning the lights down low, or wearing sunglasses may decrease the use of vision for stabilization.

Strategy Training. Training ankle, hip, and stepping strategies may begin in a voluntary manner but must progress to an automatic level of use to develop more normal balance and for real-life prevention of balance loss. Before strategy training, the clinician should be sure that the client has the ability to develop the desired strategies. The observed dominance of other strategies is appropriately compensatory, not dysfunctional, if a missing strategy cannot be effectively executed. Clients use these strategies to prevent loss of balance, so the clinician must take care not to reduce reliance on an effective strategy but to add additional strategies to the repertoire.

Ankle strategy should be practiced on a firm, broad surface. Clients can be asked to sway slowly in anterior-posterior, right-left, and diagonal directions, first to and from midline, progressing to passing midline, and finally progressing to sway toward the periphery without return to midline. Head and pelvis should be traveling in the same direction at the same time. Clients can practice standing near a wall with a table in front of them, swaying forward to touch the wall with the back of the head. Cues are given not to “bow” to the table and not to touch the wall with the buttocks. As soon as the client is able to perform this protocol, functional meaning should be added with maneuvers such as forward or lateral reaching tasks, hands over head to take things off shelves, and leaning backward to rinse hair in the shower. To improve anticipatory and automatic ankle strategy use, add slight perturbations to the body or the surface when midline, progress to gentle
perturbation when away from midline, and finally progress from predictable to unpredictable perturbations.

Hip strategy is practiced on either a narrow or an unstable surface, such as standing sideways on a balance beam, a two-by-four, a half-slice foam roller, foam, or a rocker board. The head and pelvis travel in opposite directions to counterbalance each other, in a forward bow–backward bending motion for anterior-posterior sway. Rapid sway is requested in forward-backward, right-left, and diagonal directions. By using the wall and table setting previously mentioned, clients can be cued to how to touch the nose toward the wall when simultaneously touching the wall with the buttocks. Lateral hip strategy can be trained similarly, with the client standing sideways to the wall, touching the wall with one hip and the wall with the opposite shoulder.

Sway close to the edge of the client’s limit of stability should produce a shift from ankle to hip strategy, so to enhance the use of hip strategy the client should practice sway control as far away from midline as possible without stepping. As soon as the client demonstrates the ability to perform this strategy, it should be incorporated into functional tasks such as low reaching (e.g., trunk of car, laundry dryer).

To promote anticipatory and automatic use of hip strategy, the client is in midline and given moderate, rapid perturbations to the body or the surface such that ankle strategy will be insufficient to counteract the force. Then the size of the disturbance is increased, and the client is positioned away from midline when the perturbation is given so that righting to midline is appropriate. The shift should be made from predictable (“don’t let me make you step or fall”) to unpredictable perturbations.

Stepping strategy can be practiced first from atop a step, curb, or balance beam. Both legs should be included in training because real-life situations such as a slip or trip often preclude the use of one limb and demand the use of the other. It may be necessary to fix one foot in position to prevent stepping by the less affected leg in order to allow a stepping response on the more affected leg to emerge (a forced-use paradigm). Progress is made by stepping on a level surface and then to stepping up onto a step or curb or over progressively larger obstacles (appliances cord, shoe, phone book). All directions should be practiced, including lateral and diagonal perturbations, if safe recovery from real-life unexpected balance losses is to be learned. Large, rapid perturbations are given such that ankle and hip strategies will be inadequate and stepping or reaching is demanded. Again, progress should be made from predictable to unpredictable disturbances. For any automatic postural response—ankle, hip, stepping, protective reaching—to be effective in real life, effective demonstration of the response to unexpected perturbations is imperative.

Many clients, especially those who are fearful of falling, are dependent on the use of hands for stability. Therapeutic balance retraining activities should provide the maximal level of challenge that can be managed without the need for upper-extremity support. If the client physically needs to hold on, then the activity is at too high a level and should be modified. Otherwise, what is being taught is a “hand strategy” that will not be useful if the client experiences loss of balance when nothing firmly fixed is available to grasp for stability. Extremely anxious clients may initially benefit from training with an overhead harness system that will permit hands-free motion but provide tangible reassurance that a fall will be prevented if balance loss occurs. In this case, treatment progression would include weaning the client off the use of the harness. If the only harness available is on a body-weight support treadmill or gait system, move the balance retraining to that harness. The treadmill does not need to be moving.

Gait Training. The initial focus for controlling the COG during gait is a stable base of support that can be continually reestablished quickly and reliably through stepping. Unlike standing balance, in which the base is stable and the COG moves over it, during locomotion the base is moving and the COG moves to stay over the base. Achieving a symmetrical, smoothly oscillating COG movement is the objective, with the forces of gravity and momentum being exploited.

The training is begun first in the forward direction but also includes backward and sideways directions (sidestepping, braiding, or carioca) to increase postural control demands. Challenge can be added by narrowing the base of support (tandem) or reducing the foot-surface contact (walk on toes or heels). Training to integrate postural control with locomotor skills is best accomplished not through continuous, steady-pace walking, but by starting, stopping, turning, bending, varying the speed, and avoiding or stepping over obstacles. Difficulty is added by increasing the abruptness, frequency, and unpredictability of these types of tasks and by adding tasks such as carrying or reading while walking.

Altered surface conditions (carpets, ramps, curbs, stairs, grass, gravel) or reduced lighting conditions also heighten the challenge. Head and eye movements while walking should be added as the client improves. Walking quickly while reading signs on the wall or room numbers, for example, or looking toward and away from the therapist while walking makes vision more difficult to use for stability. Walking in crowds or in busy, cluttered environments is also challenging. Locomotion training on the treadmill reduces some abnormal asymmetries and increases control of gait with increased extension of the trailing limb.116 Again, gait training specifically for balance enhancement should occur without holding onto fixed surfaces with the hands, for example, parallel bars or the side rails of the treadmill. This is because the nervous system needs to learn to solve the balance problem using the legs and trunk, not the hands.

Clients with somatosensory loss in the feet should use a cane or walker. They may not need the device for biomechanical support, but they do need to obtain as much information about the surface as possible. Through use of a cane or walker, preserved somatosensation in the hands can detect surface information that is important for balance control, and biomechanical support is available if needed in case of balance loss.

Other Considerations

Treatment Tools

Therapists use both high-technological and low-technological equipment in the remediation of balance deficits; each has advantages and disadvantages. High-technological options include accelerometers with motion biofeedback, force plate systems with postural sway biofeedback, electromyographic biofeedback, optokinetic visual stimulation (from visual
surround or moving lights), videotaping, and treadmills with biofeedback. Options for the evaluation and treatment of balance and gait deficits are expanded with the addition of advanced technology such as forceplate measures of postural sway and pressure mat measures of gait, giving the therapist a more quantitative and sensitive measurement than visual observation or timed measures. Most high-technological systems provide computer-generated reports with charts and graphs quickly. For training, overhead harness systems allow safe, hands-free practice, and computerized sway feedback supports motor learning (Figures 22-20 through 22-23). Computerized systems allow advanced monitoring of progress and biofeedback, which supports motor learning.\(^{117}\)

Figure 22-20 is an example of technology in which forceplates measure pressure-generated signals (center of force [COF]). The systems shown use height and COF data to calculate the COG, which is used to measure postural sway. The COG icon may be displayed on the monitor screen for feedback to the individual if desired. Figure 22-21 is an example of how surface motion provides both biomechanical and somatosensory challenges. Balance measurement characteristics vary: some systems measure the motion of the surface (Figure 22-21, A), whereas others use motion sensors on the body placed at the level of the COG (Figure 22-21, B). Other systems provide the ability to generate visual motion. Figure 22-22, A, shows a system with a three-sided booth with unidirectional motion combined with a moveable forceplate with unidirectional motion. Both visual and somatosensory inputs can be manipulated for testing (e.g., SOT) and training. Omnidirectional visual motion (Figure 22-22, B) can be produced by rotating display systems that are used in a dark room.

The ability to challenge balance during gait training is improved if the client is secure in an overhead harness system as seen in Figure 22-23, A and C. These systems allow hands-free training as soon as possible, to increase reliance on the lower extremity and trunk reactions critical for balance recovery strategies. Rapid and recordable measurement of gait characteristics (e.g., velocity, step length, step width) is possible with instrumented systems. Some systems are made for overground walking (Figure 22-23, B) and are portable. Other systems are incorporated into treadmills and provide feedback during gait training. All motorized systems provide the ability to manipulate the environment easily and efficiently and to graduate tasks and environmental challenges safely. Drawbacks to high-technological equipment include cost, space requirements, and operator training requirements.

Low-technological options include mirrors, soft foam pads, hard foam rollers, rocker boards, BAPS boards, tilt boards, Swiss balls, mini-trampolines, balance beams, and wedges or incline boards. All these items are accessible (low cost, easy to obtain), portable, and easy to use. The main drawbacks for low technological equipment are that it does not provide novel feedback, objective scoring, or graphic recording, and clinicians must be skilled and creative in the use of such equipment in order to provide appropriate gradation of task difficulty and environmental conditions.

**Safety Education and Environmental Modifications**

Remediation of balance deficits is not always possible, but the clinician is always responsible for ensuring the safety of each client. When permanent deficits exist, the client and the family should be taught in what environments the client is at risk (e.g., a client with vestibular loss on a gravel driveway at night), what tasks are unsafe (e.g., use a cane at night or in crowds), and what changes in the home or workplace are needed (e.g., night lights, stair stripes, raised toilet seats). Clinicians can ask the client (or family) to problem solve risky situations: “What would the client do?” Home evaluations should be followed by a list of recommended safety modifications. Falls are frightening and dangerous; clinicians should do their utmost to prevent them. If falls are likely, clients and families should be taught what to do if a fall occurs and, once the client is on the floor, how to perform floor-to-standing or floor-to-furniture transfers. Home monitoring services such as Lifeline may be indicated if the client lives alone and is prone to falling. Hip protectors will not prevent falls but do significantly reduce the risk of hip fracture.

**Home Programs**

Strengthening, stretching, posture, and endurance exercises can all be performed safely at home so that time in the clinic can be spent on balance-challenge exercises requiring supervision. Improvements in strength, ROM, posture, and endurance support improvements in balance. Many balance exercises can and should be performed at home if safety and adherence can be ensured; however, _unstable clients should always be supervised_. Standing balance tasks can be completed in a corner or near a countertop so that in case of balance loss the client can use the hands (reaching strategy) to prevent a fall if other automatic postural response strategies are inadequate. However, balance exercises should not be routinely done while holding onto countertops, furniture, or other surfaces. If the client needs to use her or his hands to perform the balance task, the task is too difficult and
should be modified so that it can be safely performed without needing to hang onto a stable object. The community setting is ideal for postural control gait training. Grocery or library aisles, public transportation, elevators, escalators, grass, sandboxes or beaches, ramps, trails, hills, and varied environmental conditions in general provide both challenge and functional relevance.

**Concurrent Tasks**
Normal balance is largely subconscious. One objective in balance retraining is to force the nervous system to solve postural control problems at the automatic, subconscious level. A great deal of practice and dual-task training are necessary to accomplish this; the conscious brain is focused on accomplishing some other goal(s) and thus balance control must be achieved at a less conscious level. Alternative tasks can be physical in nature, such as carrying a tray or dribbling a basketball, or cognitive, such as conversing or solving verbal or math problems, or a combination of physical and cognitive demands.

This objective is not universal. Clients with permanent or progressive deficits in automatic motor processing, particularly those with Parkinson disease, lose automaticity. They must learn to produce motor actions voluntarily, with attention and intention, unless there are external sensory cues to drive the motor system.

**Figure 22-21** Advanced technology to support balance and gait retraining. Other systems provide surfaces that can be made unstable (A) or made to move (B). The surface motion provides both biomechanical and somatosensory challenges. Amplitude and velocity capacity also vary from system to system. Both systems shown here provide omnidirectional motion. A, Biodex Balance System SD measures the motion on the surface, B, Proprio Reactive Balance System uses motion sensors on the body placed at the level of the COG (A, Courtesy Biodex Medical Systems, Shirley, NY; B, Courtesy Perry Dynamics, Decatur, Ill.)
Fall Prevention

Client safety is always paramount; for any client with balance deficits the risk of falls is increased and must be addressed in every clinical management program. In older adults without documented neurological conditions, falls are prevalent and lead to severe injury (including head trauma) and death. Fall risk is even greater and is especially high in persons with stroke and Parkinson disease. Fall prevention is a critical primary objective for clinicians serving clients with neurological conditions who have impaired balance and gait.

Fall risk factors are categorized as intrinsic, relating to the individual, and extrinsic, relating to the environment. Intrinsic risk factors include but are not limited to medical conditions (e.g., stroke, Parkinson disease); medications; impaired balance and gait; somatosensory, visual, or vestibular sensory loss; central processing problems; slow reaction time and other central motor deficits; lower-extremity weakness and decreased ROM; cognitive deficits; depression; urinary urgency or incontinence; and footwear. Extrinsic risk factors are hazards in the environment, such as inadequate lighting or excessive glare, slippery or cluttered surfaces, lack of handrails or grab bars, attention distracters, and timing demands (e.g., hurrying to answer the phone). The more risk factors present, the greater the likelihood of falls. Most falls in community-dwelling older adults are trips and slips and occur because of a combination of intrinsic and extrinsic risk factors. For example, a client with hemiplegia who has limited ability to rapidly and maximally dorsiflex the ankle who encounters a trip hazard such as a rumpled doormat may not be able to clear the obstacle by lifting the hemiplegic leg and foot quickly. If the number and/or severity of intrinsic risk factors is great, falls may occur without any provoking extrinsic hazard.

Additional factors influence fall risk levels. The location of the client may have an effect on fall risk. While in an institutional setting, the physical environment may be safer and the level of supervision and assistance higher, thus lowering risk. Yet if the surroundings are unfamiliar or confusing to the client, the client does not remember to call for assistance before getting up, or the environment holds barriers such as bedrails, wheelchair footrests, and so on that must be dealt with when hurrying to the bathroom, then an institutional setting may pose increased risk. The amount of supervision or assistance the client receives may alter risk level. Confused or forgetful clients in facilities with high staff-to-client ratios or who have family or caregiver supervision most of the time will have lower risk than those in facilities or homes where supervision and assistance are sparse. Lastly, the relative dependence-independence level of the client, both physical and cognitive, affects risk level. Very dependent clients who cannot get up by themselves, and very independent clients with high-level balance and
Balance and Vestibular Dysfunction

Advanced technology to support balance and gait retraining. High technology used to challenge gait. The ability to challenge balance during gait training is improved if the client is secure in an overhead harness system. These systems allow hands-free training to increase reliance on the lower extremities and trunk reactions critical for balance recovery strategies. Rapid and recordable measurement of gait characteristics is possible with instrumented systems. 

**Figure 22-23** Advanced technology to support balance and gait retraining. High technology used to challenge gait. The ability to challenge balance during gait training is improved if the client is secure in an overhead harness system. These systems allow hands-free training to increase reliance on the lower extremities and trunk reactions critical for balance recovery strategies. Rapid and recordable measurement of gait characteristics is possible with instrumented systems. 

A, **Biodex FreeStep SAS** uses overhead harness system to challenge balance during gait. 

B, **GAITRite Portable Walkway System** challenges gait during overground walking. 

C, **Biodex Gait Trainer 3 with Unweighting System** is another example of how to challenge balance during gait training. (A and C, Courtesy Biodex Medical Systems, Shirley, NY; B, courtesy CIR Systems, Havertown, Pa.)

Gait skills, are both at lower risk than clients in the middle of that spectrum. Clients who have sufficient ability to get up out of the bed or chair, and perhaps to walk, but who have impaired balance and gait skills and poor judgment or memory are at a much higher risk level.

A separate but equally important risk to consider is the risk of injury from a fall. Injury risk also depends on both intrinsic and extrinsic factors. Clients with low bone mineral density, low body mass, and impaired protective responses (automatic postural responses, especially reaching or protective extension) are more likely to be injured. Falls that occur from a greater height onto a harder surface are more apt to result in injury. An overweight client with adequate bone mineral density (BMD) who, while in her yard gardening, stumbles and falls to the grassy ground from standing height with both arms out to break her fall would have a lower risk of injury. A thin client with osteoporosis who, while at the store shopping, stumbles off a curb and falls to the concrete parking lot without getting her arms out in time to protect her would have a higher risk of injury.

Clinicians should consider fall risk and injury risk factors as they carry out their assessments and evaluation. This would begin with the chart review or history taking; as problems are noted, the clinician should be “red-flagging” those that are risk factors for falls. For example, you might note that the client is on more than six prescription medications; polypharmacy is a risk factor for falls. You also note that one of the medications is a drug to remediate bone loss, and further inquiry reveals that the client does have a diagnosis of osteoporosis, a risk factor for injury. During your own therapy assessment, you find substantial lower-extremity weakness, balance impairments, and gait limitations requiring the use of an assistive device, all major risk factors for falls. One of the identified balance impairments includes deficient automatic postural responses, a risk factor for injury. Later, during a team meeting to discuss the new client,
you learn from the occupational therapist that the home safety survey completed by the client’s spouse indicates numerous safety hazards, extrinsic risk factors for falls and perhaps injury. For fall prevention and injury prevention purposes, a list of all fall and injury risk factors pertaining to that client should be generated for use in treatment planning.

The aim of intervention for fall prevention is to eliminate or minimize risk factors, with emphasis on four risk factors that appear to be more influential than others (in community-dwelling older adults). These four interventions are exercise, medication management, home safety modification, and vision management. The single best intervention for fall prevention is exercise—specifically, individualized exercises that target balance, gait with balance challenges, and leg strength. The challenge level of the balance and gait exercises should be high. The balance and gait training program must be of high intensity and frequency and of long duration. For a reduction in fall rates in community-dwelling older adults, a bare minimum of 5 to 6 weeks, with sessions two to three times a week, is required. For more neurologically involved clients, the overall amount of practice would need to be greater. Gains that are made during therapy will not be maintained unless exercise or physical activity that includes balance challenge is continued after therapy. Clients should be intentionally transitioned from therapy to a community-based balance exercise or physical activity program as an integral part of their discharge plan. Clinicians may consider doing their last treatment or two at the community-based program to support the client through the transition and increase the probability of follow-through. It is critical for clients to persist with physical activity to maintain or even further lower their fall risk level.

The second area of intervention is medication management. This requires a team approach and tactful, professional communication with the client’s physician(s). The goal is to have the client take as few medications as possible, in the smallest doses possible, and to eliminate or when necessary replace certain drugs that are known to raise the risk of falls substantially (e.g., benzodiazepines). (Refer to Chapter 36 for a discussion of the impact of drug therapy on patients undergoing neurological rehabilitation.) Clinicians must understand that medication management for fall prevention is a difficult balancing act for the physician. For example, antidepressants and sleeping pills raise the risk of falls. Yet depression and sleep disorders are serious conditions with many negative effects, and depression, inattention, and fatigue are all risk factors for falls. Both the condition and its treatment increase risk! Clients on blood-thinning medication who are at risk for falls are also at risk for serious bleeding problems should a fall occur; the physician, client, and family or caregiver should all be alerted to this risk. Medication management guidance for fall prevention directed to physicians is available from the American Geriatrics Society.

Home safety modification is an effective intervention for those who are already at high risk for falls. Ideally an in-person home safety evaluation is performed by a trained professional, usually a physical or occupational therapist. If this is not possible, a home safety survey may be completed by a reliable source (client, family member, or caregiver). The clinician and client or their responsible decision makers should then have a frank discussion about recommended home safety modifications. The clinician should convey what is recommended and why, highlighting the benefits. However, factors such as time, expense, and personal preference also influence client and family decisions. Identification of barriers to safety modification implementation is helpful and may lead to solutions that permit initial resistance to be overcome.

Vision management is critical for any client with visual deficits. (Refer to Chapter 28 for a discussion of disorders of vision and visual-perceptual dysfunction.) These visual impairments might be at the peripheral level, such as macular degeneration, or the central level, such as homonymous hemianopsia. Occupational therapy is recommended for a visual-perceptual evaluation and potentially for low-vision rehabilitation if needed. Vision professionals (ophthalmologists, developmental optometrists), preferably those with specialization in neurological populations if indicated (e.g., TBI, cerebrovascular accident [CVA], MS), should also be involved. Objectives include maximizing vision for the client and including visual support within the home safety modification plan if needed.

Footwear assessment is important. Walking indoors barefoot or in socks is associated with increased fall risk. The footwear most highly associated with hip fractures is slippers. Shoes and slippers that do not provide adequate foot support, or that have slick soles, are unsafe and not recommended. Footwear lacking a secure back (flip-flops, mules, or sling-backs), high-heeled shoes, and platforms are poor choices for clients at risk for falls. Running shoes with very thick, cushioned soles and a heavy tread are also not ideal. The optimal shoes for fall risk reduction are well fitted with thin, hard soles. Shoes with a towel sole and a tread beveled heel are more stable on wet or slippery surfaces. Just as with home safety modifications, factors such as expense, habit, and personal preference may create obstacles to client adoption of suggested footwear changes. These obstacles should be recognized, respected, and addressed directly with professional communication strategies designed to facilitate positive behavior change.

Clinicians should assume that clients at risk for falls will fall when they are discharged home. Though we work to ensure this will not happen, we also prepare for the possibility that it will. Clients who are able must be taught how to get up from the floor independently, with and without furniture if the latter is possible. If clients cannot get up from the floor by themselves, then family members or caregivers should be taught how to assist clients to get up from the floor. This may be as simple an act as bringing a chair close to the client so the client can use the chair to get up independently. Clients at risk for falls who will be home alone for extended periods of time would benefit from a wearable home alerting system. If such a system is cost-prohibitive, the client should develop the habit of carrying a cell phone at all times. For clients without cell phones, a landline phone should be left on the floor or a chair seat so that it is within reach from the floor should a fall occur. Older clients with osteoporosis should consider wearing hip protectors. Hip protectors do not reduce the risk of falls but when properly fitted and worn may reduce the risk of hip fracture. Adoption of and adherence to wearing hip protector apparel is typically low and requires commitment and effort.
The combined aim of balance retraining and fall prevention is to assist the client to become as active as is safely possible. With improved balance and gait skills, the client achieves higher levels of function and physical activity. With attention to and emphasis on fall prevention, safety is maintained, injury is prevented, and the opportunity for improved quality of life is preserved.

Vestibular System
Kenda Fuller, PT, NCS

OVERVIEW: THE ROLE OF THE VESTIBULAR SYSTEM
The CNS integrates the information from visual, somatosensory, and vestibular inputs to determine the most appropriate response to maintain stability and homeostasis. These three senses play an important role in dynamic equilibrium (Figure 22-24). In fact, the somatosensory system is necessary to interpret vestibular information. The activity of the vestibular system must be recognized in order to interpret balance testing. This chapter provides background information that has been incorporated into the earlier portion on balance.

The role of the vestibular system is to maintain clear vision during head motion as well as to orient head and trunk in space with respect to gravity when the visual and surface references are not sufficient. Horizontal and vertical accelerations, as in riding in a car or an elevator, are also detected by the vestibular otolith mechanism as seen in Figure 22-24. The vestibular system is critical for postural control because it uniquely identifies self-motion as different from motion in the environment. Recognition of self-movement as it relates to visual movement can be disrupted momentarily in a normal individual experiencing unexpected movement in the peripheral visual environment. This is a common sensation noticed, for example, when the car next to you moves backward, and you press the brake, thinking that you are rolling forward. Unless the system fails, the vestibular system is noticed only when it is stimulated beyond the level at which it is typically activated, as in a fast spin or the drop of a roller coaster. The dizziness that occurs in the normal individual when the vestibular system is overstimulated is reflective of the dizziness that occurs when the brain encounters sudden changes or losses of input from the vestibular system.

Disorders of the vestibular system can cause devastating lack of visual stability, loss of balance, and inaccurate sense of movement. There is an initial loss of trunk and gaze stability with vestibular dysfunction that improves as a result of CNS adaptation. The CNS adaptation is critical to recovery of function. In the course of recovery, the visual or somatosensory systems may be chronically used in preference to the vestibular system, causing abnormal sensory dependence patterns. Comorbid dysfunction can affect functional recovery, especially if it affects the visual or somatosensory inputs. Prior trauma, either physical or psychological, can cause maladaptation resulting in responses to intervention that are inconsistent with typical recovery patterns.

Clinicians are exposed to patients at many different levels of adaptation, from the ones who show adequate adaptation with minimal intervention to those who have recovered only limited independence after disruption of vestibular system inputs. Successful intervention is achieved by accurately analyzing both the missing and the available components of the system, facilitating adaptation, avoiding excessive sensory substitution, and determining appropriate compensatory strategies. If maladaptation is not understood and treated properly, it can lead to frustration for the patient and clinician, resulting in less than optimal outcomes.

VESTIBULAR SYSTEM DISORDERS
There are many types of common vestibular disorders. This chapter cannot provide a total discussion of all these disorders. They have been summarized in Appendix 22-A.

RECOVERY OF FUNCTION: NEUROSCIENCE OF THE VESTIBULAR SYSTEM
Recovery of function is related to the mechanism of injury and where the damage is located. In order to understand how the system recovers, we must first understand how it works. The end organ of the vestibular system is basically a mechanical, fluid-filled system activating afferent signals that travel through the vestibular nerve to the brain stem nuclei. Figure 22-25 shows the relative relationship of the canals to the otoliths and the cochlea. This demonstrates...
why there is often a connection between loss of hearing and vestibular dysfunction, especially when the fluid mechanism is part of the impairment. Box 22-1 describes the sensory components of the vestibular system. At the level of the nuclei, the brain stem receives input from the other sensory systems related to orientation of the head and body. The combined input is further modulated by the cerebellum, providing further calibration. Purkinje cells in the cerebellum provide inhibitory control of the vestibular nuclei. The flocculonodular lobe and medial zone of the cerebellum affect postural control. Input continues to the cortex via the vestibular projections (Box 22-2).

**Recalibration at Rest**

The tonic firing of the vestibular system when the head is in a neutral nonmoving state is symmetrical on both sides of the system at approximately 50 spikes per second. The brain is able to compare this symmetrical resting level tone to the information coming from the visual and somatosensory systems' feedback about the position and movement of the head.

When there is disruption of signal from one side of the vestibular pathway, it will change the relative input into the CNS, resulting in a perception of the head rotating toward the intact side when the head is not actually moving (Figure 22-26). Initially, as well, there will be a phenomenon of spontaneous nystagmus, a reflex-driven movement of the eyes. In an acute asymmetrical vestibular system disruption, the eyes will move away from the perceived direction of head motion, and that movement of the eyes will cause a sensation of dizziness with the head still, eyes open. The brain quickly identifies this as an abnormal state and begins CNS recalibration so that the vestibular system input from each side becomes calibrated to match the visual and somatosensory system input. The system is able to determine that despite the uneven signals, the head is not really moving. There is usually adequate central adaptation to stop the spontaneous nystagmus in a lighted environment within 3 days. The spontaneous nystagmus may continue to be active in a dark room, and there may still be a sensation that the head is rotating when the eyes are closed for weeks after the insult. Increasing somatosensory input about stability can help in the central recalibration process. Input through the joint surfaces by establishing a stable joint reference can facilitate calibration. This appears to be most effective through mechanical pressure through the top of the head or with the use of weights on the shoulders to increase the vertical reference of the spine in a neutral position. Figure 22-27 shows how weights are placed on the shoulder to provide somatosensory input. The brain can then match or recalibrate the abnormal perception of head movement induced by the inaccurate vestibular system to the correct reference of the stable somatosensation. It is critical in the rehabilitation process to achieve accurate CNS recalibration with the head at rest before initiating intervention that requires movement of the head.

**BOX 22-2 ■ POTENTIAL LOCATION OF LESIONS THAT MAY AFFECT THE VESTIBULAR SYSTEM**

- Vestibular end organ and vestibular nerve terminals
- Vestibular ganglia and nerve within the internal auditory canal
- Cerebellopontine angle
- Brain stem and cerebellum
- Vestibular projections to the cerebral cortex

Head Movement and Gaze Stability

As the head starts to move, the signal from each part of the vestibular system activates as a result of fluid movement against the cupula. The direction of movement is determined by the relative firing pattern of the vestibular system from each side of the head. The vestibular system on the side toward the movement increases in firing, and the side opposite decreases its firing rate. The resulting signal to the brain stem drives the VOR to move the eyes in opposition to the head movement, and the gain remains 1:1. Figure 22-28 shows the neural connections involved in activation of the VOR. If the vestibular system does not drive the eyes to the correct position for stable gaze, the result is vestibular-driven oscillopsia, and again, objects can appear to move as the head moves. This disorder has significant functional implications and works in conjunction with both smooth pursuits and saccades to interpret the relationship of the body to the environment (Figure 22-29).

Figure 22-26 Patterns of excitation and inhibition for the left utricle and saccule when the head is upright (A), tilted with the left ear 30 degrees down (B), and tilted with the right ear 30 degrees down (C). The utricle is seen from above and the saccule from the left side. (From Haines DE: Fundamental neuroscience for basic and clinical applications, ed 3, Philadelphia, 2006, Churchill Livingstone.)
The VOR is reported as abnormal only if there is loss of gaze stability, or blurring of target objects with head movement at 1 to 3 Hz. Rotation or pitch of the head during testing of the VOR may cause dizziness because of the differences in firing patterns from each ear that are not yet efficiently calibrated. This is especially noted when the head is moving in the direction of the abnormal ear. It is important to note that head motion–provoked dizziness can persist even when gaze stability has normalized.

The clinician must also be aware that the peripheral visual field will appear to move in the opposite direction as head movement during these testing procedures. This normal visual phenomenon can cause dizziness in the patient with visual dependence or visual motion sensitivity (described later). It is the vestibular system that provides the reference of head movement and position so that the perceived movement in the environment is properly identified.

The quality of somatosensation in the spine and muscles of the upper body can contribute to dizziness with head motion. The vestibular nuclei have the job of integrating somatosensory information on its way to the cortex. There must be adequate input from both systems to distinguish between head-on-body and body-on-head movement. Impaired somatosensation, pain, and guarding of movement will disrupt the accuracy of calibration related to head movement. The patient who has an abnormal VOR will be constantly decelerating head movement to less than 2 Hz in order to prevent blurred vision. That unconscious deceleration by the muscles in the neck can cause stiffness and decrease the sensitivity of the somatosensory mechanisms in the neck. Two simple tests will alert the therapist to abnormalities of head motion related to the quality of somatosensation. Holding the head upright and still, in gravity-neutral position, while the patient rotates in a chair (body on head) provides information about the somatosensory reference. The movement may elicit dizziness if the somatosensation is impaired. If the patient has been relying on somatosensation as a primary reference for head position, there may be resistance or guarding against allowing the body to move in a direction different from the direction of the head movement.

Rotating in a chair at 1 to 3 Hz and allowing the head to move at the same speed as the body will eliminate somatosensation reference through the neck receptors and isolate the vestibular system response to rotation of the head. This should
be done with the eyes closed to eliminate the sense of visual motion. Movement at this speed will cause an increase in dizziness even in a normal system, but it should resolve in less than 10 seconds. If the dizziness persists for longer than 15 seconds, it is considered to indicate abnormal vestibular calibration.

**Head Position Changes**

Head position changes in reference to gravity can cause dizziness as a function of the vestibular system under certain circumstances. The most common form of head position dizziness in adults is BPV (see Appendix 22-A). In this condition, debris (otoconia) from the utricle moves into the semicircular canal, and there is suddenly mass in a system that is designed to calculate only fluid pressure changes in response to head movement. The added mass causes excessive deflection of the hair cells in the cupula when the head is moved into a gravity-dependent position. The otoconia move in the direction of gravity through the endolymph, causing a pull on the cupula and increased firing of the hair cells as if the head were moving quickly in that direction. Figure 22-30 shows the movement of the otoconia in relationship to head movement in a gravity-dependent state. The brain activates the VOR in response to the message that the head is moving quickly, and there is nystagmus based on the same mechanism as described previously. The nature of this nystagmus reflects the canal in which the debris is floating. As soon as the otoconia come to rest, the pressure on the hair cell is gone, and the nystagmus subsides. This takes about 20 seconds. There is no nystagmus until the head is moved into another gravity-dependent position causing the otoconia to roll through the canal.

**Top-down Reference for Postural Control**

The most important role of vestibular information for postural control relates to orientation of the head and trunk in space with respect to gravitational forces. Orientation to gravity is most critical when balancing on unstable surfaces when vertical and horizontal visual reference is not adequate. The vestibular system provides a top-down reference for the head and trunk stability in line with gravity while the leg segment is coordinated to maintain surface reference. Vestibular inputs are critical to determine whether the body is swaying or the surface is perturbed. The conscious perception of verticality used to orient to gravity when the support surface is perceived to be unstable is provided by the vestibular system. Vestibular inputs are used in order to recognize the changes in angle of the support surface. Surface perturbations or oscillations provide a method to examine the ability of the vestibular system to maintain the head and trunk in gravity-neutral position as the legs move in reference to the platform movements. When standing on a surface that tilts both anteriorly and posteriorly at 4 degrees per second, patients with bilateral vestibular loss will lose balance and fall. A normal person should be able to position a hand-held rod in vertical while standing or sitting on an oscillating surface, irrespective of the angle of the surface, even with eyes closed. Individuals with loss of orientation to gravity will orient the hand-held rod with respect to the angle of the moving surface.

It is important to remember that at the same time the vestibular system is activated in this moving surface condition, the somatosensory system is still providing feedback about the relationship of the head that is provided by vestibular inputs to the base of support. Resulting patterns of muscle activation reflect vestibular and somatosensory integration to maintain continuous upright postural control. As a surface rotates to greater degrees, there is more weighting of the system away from the somatosensory reference toward the gravity reference. Patients with uncompensated vestibular dysfunction will report lack of awareness of angle changes when standing on an oscillating support surface. Therefore, instead of changing the ankle angle to
adjust to the tilt, the torque around the ankle remains locked, holding the leg, trunk, and head at 90 degrees to the surface. The head then follows the direction of the surface tilt as seen in Figure 22-31. As the surface tilt angle exceeds 8 degrees, the individual who cannot activate gravitational reference or adjust the ankle angle will be unable to maintain balance. Lateral tilt can activate the system in the same way; with the head following the direction of the downward tilt, the weight is typically shifted to the downward-most leg. Patients report lack of awareness of the movement generated. Figure 22-32 shows the abnormal shift of weight as the patient attempts to orient to the surface rather than gravity.

**Bottom-up Reference for Postural Control**

The somatosensory system can determine the orientation of the head in reference to the surface through cutaneous, proprioceptive, pressure, and stretch receptors of the muscles and joints, primarily related to pressure through the balls of the feet. Although overreliance on this surface reference can be destabilizing in some conditions, it contributes to balance when the surface is stable or moving slowly (at less than 4 degrees per second). At the other end of the spectrum, in very fast oscillations the muscle spindles provide stabilizing information that can contribute to head and trunk stability.

It is critical to remember that the vestibular spinal system also activates the neck muscles in response to head perturbations and modulates somatosensory-driven activity of muscles in the neck. When the vestibular system function is missing or inaccurate, there is abnormal muscle activation in the muscles of the neck. One way this function can be tested is by observing head-righting response when a patient has vision blocked and is tilted while sitting on a tilt board so that the perturbation starts at the surface instead of the head. In the patient with vestibular dysfunction, when gravity vertical reference is lacking, lateral head righting back to center, or neutral is inadequate. This can be a result of co-contraction of the neck muscles to lock the head into position, with the trunk maintaining the same tilt as the trunk. The head stays in reference to the surface in much the same way as described earlier regarding locking of the ankle joints. This is evidenced in higher-level activities that require gravity reference such as tandem walking in visually stimulating environments or with vision occluded. As the patient tries to use somatosensation to determine head position instead of gravity reference, the head becomes locked onto the trunk through abnormal muscle activation. The narrow stance limits the contribution of surface reference in the lateral plane, and the patient must take a step out to control the excessive lateral tilt of the trunk and head. Figure 22-33 represents the abnormal and normal views of head righting in both sitting on a tilted surface and standing in tandem. It is the vestibular inputs that should drive the appropriate head righting and resulting postural strategies that are required in these conditions.
Having even the slightest touch reference so that the somatosensory system can orient the trunk through upper-extremity joint position sense is another way to substitute somatosensation for vestibular reference. The position of the head and trunk can be determined by this touch even when the vestibular system function is missing and eyes are closed. Because the arm stabilizes the trunk more than the legs do, reaching for a stable surface is a common way to maintain balance when challenged. The therapist must recognize when the patient is using this touch reference to substitute for gravity. This is why allowing a patient to touch a stable surface during balance training should be quickly eliminated from intervention to avoid dependence on surface reference when attempting to activate the vestibular system.

When the brain is not able to use somatosensation to identify the relationship between appropriate body segments and the surface, the patient often will report feeling light-headed or having the sense of floating. When somatosensory inputs from the neck are reduced, absent, or distorted, the result is poor spinal segment stabilization. Excessive muscle activity, including co-contraction of the sternocleidomastoid (SCM), levator scapulae, upper trapezius, and superficial neck extensors indicates poor stability, altered afferents, and recruitment patterns that are ineffective. Nociception from cervical segments can create “noise” in the postural control system contributing to dysmetric postural responses and nausea. Impaired cervical afferents will cause changes in cadence and length of stride when neck motion is introduced to gait. Diminished gait measures have been seen on the DGI in the presence of neck pain. When abnormal somatosensation is concurrent with CNS vestibular adaptation, the result is less than satisfactory. Because brain pattern learning is task specific and dependent on high repetition, it is not helpful to practice poor motor recruitment patterns during balance retraining.

**Visual Reference for Postural Control**

Orientation of the head in space is possible through predictive control of vision. A stable environment provides visual vertical and horizontal references for balance. Patients with vestibular loss are able to substitute vision for vestibular reference, even during surface perturbations. Destabilization occurs when the peripheral visual references are moving slowly or are not in alignment with gravity. When eyes are tracking something moving in central gaze field, the background or peripheral visual field will appear to move in the opposite direction. In the patient with lack of gravity reference, when performing diagonal smooth pursuits, postural adjustment patterns are activated as if the room were tilting, because that is the dominant sensory reference being used. The patient is pulled off balance when aligning himself or herself with the apparent visual vertical. This is most pronounced and can be tested easily when a patient is standing...
on a compliant surface, tracking a target moving in a figure-of-eight configuration. Head and trunk sway match the apparent visual field movement instead of actual gravity vertical in the patient who is visually dependent. This test can be used in a clinical battery to determine the level of visual dependence or substitution related to lack of gravity reference. Figure 22-34 shows the effect of visual dependence on head position and the resulting balance responses.

Visual disorders can disrupt balance, cause sensation of dizziness, and lead to limitation of function. Accurate evaluation of the visual system is critical in differential diagnosis (see Chapter 28 on disorders of vision and visual perception). Disorders of convergence are common in the vestibular-deficient patient and can cause delay in the process of adaptation. Sensitivities to physiological diplopia develop, causing visual motion hypersensitivity during daily activity (Box 22-3). Remember, too, that abnormal responses in neck muscle activity associated with eye motion have implications for control of posture and movement. The smooth pursuit neck torsion test (SPNT) is used to delineate abnormal cervical afferent influences on oculomotor function from vestibular influences (Box 22-4).

**Figure 22-33**  A, When surface reference is used in preference to vestibular cue, the head remains in alignment with the surface. B, As the patient is able to regain vestibular function and gravity reference, the head remains in alignment with gravity, as a head-righting response. C, Lack of head-righting responses can cause excessive use of upper-extremity activity to try to reference to the surface, with bottom-up firing patterns; hip strategy is activated but inefficient. Abnormal reference patterns result in loss of balance in tandem stance with eyes closed. D, When the vestibular reference is restored, the head remains over the feet, so balance is restored. This is why it is important to observe the angle of the head during examination of tandem stance or gait. (Courtesy Ray Hedenberg, IRB Solutions, Silverthorne, Colo.)

**Figure 22-34**  When the visual reference is dominant for head position, the position of the head changes to match the tilted peripheral visual reference that results from the eye following the thumb in a figure-of-8. A, The head tilts off center as the perception of the visual field tilts. B, If the vestibular system is dominant, suppression of the apparent shift in the visual field allows the head to stay in alignment over the base of support. (Courtesy Ray Hedenberg, IRB Solutions, Silverthorne, Colo.)

**BOX 22-3**  PHYSIOLOGICAL DOUBLE VISION

- Everything in front of and behind the central focal point is perceived as double.
- The closer the focal point, the more distance appears to be between the perceived double images.
- As the central focal point moves in space, the background image appears to move.
Sensory Substitution for Postural Control

When, as noted several times earlier, critical information from one system is absent or inaccurate, the CNS will begin to rely more heavily on the other systems for necessary reference. Although this is used initially to provide stability during the recalibration process, it can limit adaptation over the course of recovery. Visual or somatosensory dependency patterns develop when the patient persistently makes use of either or both of those systems in preference to vestibular references when the most efficient reference for the environmental condition would be the vestibular system. This phenomenon has been identified in individuals with unilateral vestibular loss, thought to be compensated for. On testing there was an average of only 50% use of vestibular unilateral vestibular loss, thought to be compensated for. On testing there was an average of only 50% use of vestibular vestibular system weighting (trunk in gravity neutral), resulting in trunk sway in reference to the surface tilt, when tested on a rotating (tilting) surface at 8 degrees. Individuals with normal functioning systems showed 100% reliance on gravity by the time the surface made the 8-degree rotation, with minimal head and trunk sway following the surface tilt.

Dependency patterns are typically observed in an individual who does not recover satisfactory adaptation and integration of the sensory systems required for normal balance responses in a variety of environmental conditions. Clinically, these substitution patterns often manifest as hyperreliance on vision or somatosensory cues even when the vestibular system may have adequate potential for recovery. When given standard vestibular rehabilitation, these patients often do not recover a full return to activity and are left with functional limitations or symptoms that have a negative impact on their lives. They may experience discomfort every time they close their eyes or may find it impossible to walk down an incline in a visually challenging environment. Increased vestibular weighting can improve the ability to accomplish ADLs and improve balance confidence. Interventions are now possible that provide both the therapist and the patient with feedback regarding trunk movement during surface perturbations.

Inadequate Use of Available Sensory Reference

Central maladaptation is a term used for what appears to be a condition that limits the use of any of the sensory systems so that each system seems to be inadequate for reference. The vestibular, visual, and somatosensory systems may test normal, but the individual is not able to use them adequately for functional activity. Patients report chronic subjective dizziness and have a tendency to develop hypersensitivities to stimuli in their environment.

Hypersensitivity patterns result in a patient who is intolerant of typical environmental conditions that include apparent visual motion, ground vibrations, or conflict between sensory references. Avoiding provoking environments such as airports or malls, wearing dark glasses inside, limiting driving, and using bracing techniques for balance are common behaviors in this group of patients. Box 22-5 presents conditions that may drive hypersensitivities. These patients have typically lost their jobs and generally underperform in life roles. Routine vestibular rehabilitation is usually not successful. Unless sensitivities are identified at initial presentation, a patient in this category may become recognized only when several treatment regimens fail. Based on the status of normal test results for individual systems, the patient has often been told that there is nothing wrong and therefore the problem is “in his head.” Indeed, this category of patient often has an overlapping psychological disorder that should be treated concomitantly. Anxiety, depression, posttraumatic stress disorder, and a history of physical or verbal abuse are common comorbidities that will affect intervention and successful outcomes. It is sometimes possible to identify the condition within the initial evaluation. These patients often report abnormal sensations with the head at rest with eyes closed, such as “flickers,” “explosions,” or “racing,” that do not reflect vestibular or somatosensory deficits. These patients will often demonstrate fear of the testing process but perform better on the higher-level tests of balance, such as eyes closed on foam, especially when distracted by a concurrent mental task. Visual motion hypersensitivity during oculomotor testing is common, and excessive startle is often seen during tests of head righting.

Vestibular Contributions to Movement

Vestibular system losses can result in motor responses that are larger than necessary for the task, which can predispose a patient to falling. This can be seen in the gait cycle when the body’s center of mass moves faster and farther than the individual can control. This movement appears similar to that of the patient with cerebellar dysfunction (see Chapter 21), and indeed may represent the loss of vestibular input to the Purkinje cells in the cerebellum that would normally modulate vestibular pathways. The earlier portion of Chapter 22, which discusses balance, describes automatic postural responses and describes balance testing in detail. It is important to understand the role of the vestibular system in movement

### BOX 22-4 SMOOTH PURSUIT NECK TORSION TEST (SPNT)

| Test: Smooth pursuits tested in head neutral and then compared with head rotated right and left |
| Findings: Compare gain in three head positions |
| Considerations: Shows relationship to cervical pain, proprioception, and oculomotor control |

### BOX 22-5 ENVIRONMENTAL CONDITIONS THAT MAY CAUSE VISUAL MOTION HYPERSENSITIVITIES

- Grocery stores—cans and boxes appear to be moving backward when one walks down aisle
- Airports with moving sidewalks
- Malls with open walkways and glass elevators
- Disco lights
- Escalators, if the “down” and “up” escalators are side by side
- Department Stores, especially during holidays or when displays are moving
- Large “box” stores where the ceiling is unusually high
- Large-format TV and movies, especially IMAX or 3D
- Walking outside when the wind blows the tree limbs
- Driving in rain or snow with windshield wipers active
disorders related to balance. Patients with vestibular deficits typically rely primarily on their ankle strategy, which permits the head to remain aligned with the body and sustains congruence between vestibular and somatosensory inputs, with the somatosensory system being the dominant reference. Use of hip strategy may be modified or limited in the vestibular-deficient patient because when the head is moving in the opposite direction as the COG, vestibular and somatosensory inputs are not congruent. However, some patients demonstrate excessive use of hip strategy on a level surface when an ankle strategy would suffice. This often is related to a maladaptation or somatoform dizziness.

The vestibulospinal system is responsible for initiation of muscle activity in the neck in response to perturbations of the head as stated earlier. Abnormal integration of the vestibular responses can be seen in excessive co-contraction of the muscles of the neck when attempting to stabilize on unsteady surfaces. Responses to postural perturbations that start at the surface instead of the head may be exaggerated and poorly timed in the patient with insufficient use of vestibular system input. Understanding the critical link between the sensory input and motor output of the structures in the tibular system input. The vestibulospinal system input. Understanding the critical link between the sensory input and motor output of the structures in the neck in relation to VSR activity is critical. Comorbid dysfunction of the cervical spine can negatively affect the reactions driven through the vestibular and somatosensory systems.

EXAMINATION OF THE VESTIBULAR SYSTEM AND DEVELOPMENT OF SPECIFIC MOVEMENT DIAGNOSES

Assessment of eye movement control can help diagnose dysfunction of the peripheral and central vestibular pathways. In particular, tests for a specific type of abnormal eye movement called nystagmus should be performed in clients with dizziness and those with known neuropathology involving these pathways. Nystagmus is involuntary, rhythmic oscillation of the eyes, with movement in one direction clearly faster than movement in the other direction. The client with nystagmus will also usually report vertigo. There is more than one type of nystagmus; identification of the particular type can direct the clinician toward the area of dysfunction. Visually induced, optokinetic, and end-gaze nystagmus should not be confused with conditions having a vestibular cause.

Spontaneous Nystagmus

Spontaneous nystagmus results from imbalance in the vestibular signals through their transmission to the oculomotor neurons. This imbalance produces a constant drift of the eyes in one direction interrupted by brief, fast movement in the opposite direction. Spontaneous nystagmus occurs after acute vestibular lesions and usually lasts approximately 24 hours. Peripheral versus central lesions may be distinguished by asking the patient to fix his or her gaze on a stable target. Nystagmus from peripheral vestibular lesions is easily inhibited with visual fixation. Nystagmus caused by central lesions of the brain stem or cerebellum is not easily inhibited with visual fixation.

Positional Nystagmus

Positional nystagmus is induced by a change in head position. Nystagmus caused by stimulation of the peripheral semicircular canals from movement of the otoconia or canals typically lasts up to 30 seconds and then dissipates. Static nystagmus occurs with lesions to the peripheral otolith system through connections in the vestibular nuclei and cerebellum. It is provoked with change of head position in relation to gravity and continues as long as the position is maintained, although it can fluctuate in frequency and amplitude. Nystagmus caused by central vestibular system damage lasts minutes or longer before abating.

Gaze-Evoked Nystagmus

Gaze-evoked nystagmus occurs when clients shift the eyes from a primary central position to a second location. It is caused by the inability to maintain stable gaze position, and the eye drifts back toward the center or primary position. Usually indicative of a CNS problem, it is common in MS, brain injury, and congenital lesions.

Video Nystagmography

Video nystagmography (VNG) captures eye movements related to vestibular dysfunction using video goggles or electrodes surrounding the orbit of the eye. Oculomotor testing is performed to determine the ability to move the eye at normal speeds. Abnormal responses can indicate central dysfunction. Another component of the VNG is the caloric test, in which warm and cold air are introduced into the external ear canal to manipulate the fluid in the horizontal canal to isolate the ear and indicate the relative function on one side compared with the other. Central disorders will produce nystagmus patterns that are different from those related to a peripheral lesion.

Vestibular-Evoked Myogenic Potential

Vestibular-evoked myogenic potential (VEMP) is based on the principle that the saccule is sensitive to sound and responds in a similar fashion to clicking sounds as it does to tilt. A click produced in the ear stimulates the saccule, which in turn inhibits the synchronous discharges of muscles in the SCM on the same side. The rate of firing or tone of the SCM is inhibited during the recorded sounds, and this change is captured using surface electromyography (sEMG). The response in one ear can be compared with the response on the other side in the same person. VEMP findings are considered to be abnormal when they are very asymmetrical such that one side is more than twice as large as the other, low in amplitude, or absent. It is thought that this inhibition allowed the head to turn reflexively to sound, as was critical for survival of early humans. An abnormal VEMP can indicate ipsilateral lesion in the saccule, the inferior vestibular nerve, the lateral vestibular nucleus, or the medial vestibulospinal tract. Conversely, dysfunction of the motor neurons of the SCM will cause abnormal findings that are not related to vestibular disorder.

Subjective Visual Vertical

Subjective visual vertical (SVV) is used to test the degree of ocular torsion present in unilateral lesions. The SVV is tested in absolute darkness or an environment that prevents visual reference to vertical. The patient is asked to orient a rod to gravity, and the degree of off-axis tilt represents
the torsion of the eye that is common in acute unilateral lesions. 154

Gaze Stability and Vestibuloocular Reflex
The ability to hold the eyes fixed on a target while the head is moving is known as gaze stabilization. To test the accuracy of the vestibular system gain, the head is rotated or moved up and down at a rate of about 2 Hz. This is the rate at which the head moves during typical daily tasks, moving up to about 3 to 4 Hz with activities such as sports. When an individual is unable to achieve similar clarity of vision at rest and at 2 Hz, it would be expected that the VOR is not sufficiently calibrated.155 If the image blurs, the gain of the system is abnormal, meaning that the vestibular system is unable to move the eyes at the exact speed in the opposite direction as the head movement. The ratio of eye velocity to head velocity is known as the gain of the VOR. The gain of an intact VOR is usually equal to one, which means movement of the eyes is equal to the movement of the head. 156

Testing of dynamic visual acuity assesses the acuity that can be obtained during a specific rate of rotation of the head. It can be tested with manual head turn using a Snellen eye chart (the same chart that is used to determine visual acuity, with normal vision recorded as 20/20) with the patient reading the smallest line that is comfortable, then having the head moving at 2 Hz in attempts to read the same line. 157 When acuity drops more than three lines, it is clear that the patient will be unable to maintain visual acuity during typical daily activity. Quantified dynamic visual acuity can be recorded as the logarithm of minimal angle of resolution or LogMAR. This can be tested and quantified by use of equipment such as inVision (NeuroCom International). Gaze stability can also be quantified using the same equipment, but the measure is one of function, reporting the head speed that can be obtained while maintaining gaze stability. This is a good way to clarify the amount of deceleration that is necessary in order for the patient to maintain proper vision. Figure 22-35 shows testing and treatment available using quantified dynamic visual acuity.

Vestibuloocular Reflex Cancellation
VOR cancellation reflects the ability to synchronize simultaneous eye and head movements in the same direction and is associated with the ability of the brain to suppress the VOR. This function allows an individual to track an object while moving the head at the same speed. Testing results are reported as normal if the eye can remain in the center of the orbit as the head and eyes track an object as it moves across the visual field. If the central integration capabilities are abnormal, the client will not be able to override the reflex activity and cannot keep the eye and head moving at the same rate in the same direction.

Gait
Vestibular control of position for the upper body and head appears to be separated from the lower body in gait in a similar pattern as noted during perturbed stance. Head and trunk stability remain constant throughout the phases of gait, and vestibular inputs appear to be most critical during initiation of gait, toe-off, and heel strike. Vestibular information contributes to the planned foot trajectory and placement of the foot to prevent disequilibrium. It is interesting to note that during steady-state gait, and even more so with running, vestibular contribution appears to diminish in importance. This may be because running is so highly automated and the trajectory remains fairly steady. 157

The gait pattern reflected by vestibular dysfunction, or lack of integration, involves flat-foot gait with minimal heel strike, abnormal foot placement requiring larger-than-normal trunk adjustment. In order to control the position of the trunk, the base of support is widened. Speed of gait is another indication of vestibular function from the perspective that patients with bilateral vestibular loss demonstrate a slower self-selected speed. Typically, increased double-limb stance time and decreased stability at heel strike are present. 158 Walking with head turns becomes even more challenging as the vestibular system is activated and the somatosensory and visual systems are disadvantaged. Vestibular contributions to stability during transitions from sitting to standing, initiation of gait, and abnormal foot placement can be identified during standard tests such as the TUG, the Tinetti, and the DGI. Scores are adversely affected when vestibular system functions are diminished. The FGA was developed specifically for use with patients with vestibular disorders. 159 For a more complete description of tests of balance, see the earlier portion of Chapter 22.

Movement diagnoses related to vestibular examination are presented in Box 22-6.

**Box 22-6 ■ Movement Diagnoses Related to Vestibular Examination**

- Spontaneous nystagmus inhibited by fixation
- Sensation of motion with body held still
- Instability or dizziness during head motion
- Loss of adequate head righting
- Head position dizziness
- Dependency patterns
- Inadequate use of available sensory reference

**Figure 22-35 ■ Quantified dynamic visual acuity is possible with systems such as inVision. (Courtesy NeuroCom International, Clackamass, Ore.)**
INTERVENTION

Positional Dizziness

The Hallpike-Dix maneuver is a positional test used to determine if otoconia are present in the posterior or anterior semicircular canal. Figure 22-30 demonstrates the position of the head and movement of the otoconia. A positive response is a delayed nystagmus of about 3 to 15 seconds, which determines potential diagnosis of BPV.

To test, the client is positioned in long sitting on a mat or plinth such that, when supine, the head and neck extend over the upper edge of the surface. The examiner holds the head of the sitting client between both hands and then rapidly moves the client backward and down with the head turned to the side and the neck extended 30 to 45 degrees below the horizontal position. The head is held in this position for 20 to 30 seconds. The examiner monitors for symptoms of vertigo and observes the eyes for nystagmus.121

When the Hallpike-Dix test position indicates BPV, specific, highly effective procedures can be performed in the clinical setting to remediate the disorder.160

Canalith repositioning is a series of passive movements designed to move loose debris (otoconia) through the canal and back into the otolith. The client is first brought down into the extended and rotated position that causes the nystagmus and vertigo (the positive Hallpike-Dix position). The head is held in that position until the symptoms fade completely or for 60 to 90 seconds. The head is maintained in extension and then slowly rotated toward the unaffected side and kept in that position for an additional 1 to 2 minutes to allow movement of the otoconia through the canal. The client then rolls so that she or he is side-lying and the head is turned to a 45-degree position relative to the ground. This position often produces more vertigo and nystagmus as the otoconia continue to move through the canal. In the next movement, the head is tipped toward the chest and the client is assisted into the sitting position. Figure 22-36 shows the sequence of the Epley maneuver. The client must then follow specific instructions for 24 hours.161 These include avoiding forward, backward, or lateral head tilts or bending activities. Clients should also sleep with the head elevated to at least 30 degrees and avoid turning to the involved side.162

When the BPV is within the horizontal canal, dizziness or vertigo is reported when rolling, especially if the head is elevated on a pillow because that puts the canal in a position perpendicular to the ground. The symptoms are reported when the head is turned in either direction, but the side that triggers the worse symptoms is thought to be the side of the dysfunction.

Horizontal canal BPV is tested for in the supine position with the head held in 30 degrees of flexion to keep the lateral canal perpendicular to the ground or in the neutral position for ease of positioning. The head is then turned in each direction and the eyes observed for horizontal nystagmus. This must be distinguished from static positional nystagmus by the fact that the nystagmus will fatigue if it is caused by movement of the otoliths, but otherwise persists.163

The repositioning intervention then begins with the client supine with the head turned toward the more affected ear. The head is then turned away from the affected ear and the client is slowly rolled 360 degrees (essentially staying in the same place) until the head is returned to the original position. The client sits back up with the head tucked. Side tilts of the head, as well as forward and backward movements of the head and trunk, are avoided for 24 hours.164

Position-provoked dizziness may alternatively be related to canal sensitivity or abnormal firing through the brain stem when BPV is not found to be the cause. In this case, exercises should be done to increase the client’s tolerance to the provoking position(s). This involves having the client perform the provoking positions to give the CNS the opportunity to adjust to the sensation that the position triggers. Rolling on a bed or spinning in a chair can help adapt when stimulation to the horizontal mechanism is disrupted. In cases of maladaptation causing sensitivity of head position, moving gradually into the position of discomfort while minimizing input from the other sensory systems can be successful. In addition to exercise sessions, incorporating the provoking positions into daily activities is also important.

Adaptation

Adaptation represents the highest level of recovery in the patient with a vestibular dysfunction, and therefore as much adaptation as possible should be facilitated for the final outcome.129,133 As noted earlier, the patient may be at any level of adaptation when intervention is initiated, and it is critical to be able to recognize the symptoms and behaviors associated with lack of adaptation and those that represent sensory substitution. Overdependence on nonvestibular sensory reference must be extinguished. Isolating specific components of the symptoms reported and understanding how impairments can manifest across several different testing procedures will guide intervention. Activation of an error signal starts the recovery process, and the environment must be carefully manipulated to challenge the patient at the right level for the correct impairment. Substitution strategies must be eliminated during exercise even if they are still in use during activity. To stimulate the use of vestibular inputs for adaptation of the CNS, environments are designed to disadvantage the eyes for and somatosensory. Practice can be on unstable or compliant surfaces, with vision either absent or destabilized by eye and head movements, progressing to optokinetic stimulation.140,165,168 Central dysfunction will negatively affect recovery rate, and knowledge of the degree and form of central disorders is important to determine prognosis and modify interventions. Psychogenic disorders will also affect the process of recovery and need to be addressed with the appropriate professional support.

When the integration of vestibular and somatosensory inputs is not congruent even at rest, there is a reported sensation of movement inside the head when the body is held at rest in supported sitting. In this instance, enhancing the somatosensory input by weighting through the spinal column or having the patient lie on a firm surface should be part of the initial intervention. This allows the vestibular system to calibrate using somatosensory input as a reference. This activity, known as settling, is a good way to allow the patient to manage symptoms when they have been exacerbated by activity. Use of distracting mental tasks pushes the adaptation to the subconscious level. Figure 22-27 shows the setup for weighting the spine to encourage settling of symptoms.

On the other hand, if the use of weights increases the sensation of movement, the clinician should suspect abnormal central sensory weighting of somatosensory inputs.
Slow progressive introduction of weights may be necessary to achieve decreased sensation of movement.

VOR adaptation requires movement of images on the retina, or retinal slip. Therefore intervention begins with head movement at the speed that allows stable vision. Adaptation of the VOR is accomplished by having the patient move his or her head while trying to maintain gaze stabilization by keeping a stationary object in clear focus. As the system adapts, speed of head movement increases, with the goal of achieving head movement at 2 Hz without the object blurring. Initially the client can focus on the thumb or a business card held at arm’s length. The activity is progressed to a higher level of difficulty by adding a background visual stimulus such as a television set or a visually complex environment. Gaze stabilization with head turns while standing on an uneven surface or while walking creates a higher-level challenge. Many clients have avoided head movement, so simply turning the head may initially trigger dizziness. As stated previously, dizziness with head motion should not be confused with abnormal VOR; in VOR dysfunction the visual image blurs as the head moves.

As stated previously, the vestibular system provides a top-down point of reference that the somatosensory system uses to prevent the head and trunk from aligning with surface changes. Perturbations in the form of oscillating surfaces provide a mechanism to activate the gravity receptors, and feedback about the alignment of the trunk to gravity neutral can help to discourage surface dependence when it should not be the dominant reference.

Ineffective head-righting responses observed during sharpened Romberg or standing on a narrow surface should be treated as such and activated for efficiency starting in a sitting tilt. Activities that require quick changes of position in a superior or inferior direction, such as a lunge or going up and down stairs, can be difficult when the otoliths are damaged. Good program components for otolith stimulation are activities involving up-and-down body movements. Examples include sitting to standing, seated bouncing on a Swiss ball, and standing bouncing on a mini-trampoline, all with eyes closed to eliminate use of vision for stability. Certain positions or movements of the head during upright activities can affect balance if just one part of the vestibular system has abnormal function. If the otoliths are damaged or hypersensitive, a voluntary lateral tilt of the head when standing with the eyes closed can cause destabilization.

A vestibular adaptation program should challenge the patient at the limit of his or her ability. Clients often choose
to do the easiest exercise and avoid the more difficult exercises if they are not educated about the need to trigger the symptoms. Conversely, if the challenge is too far above the ability of the patient, the CNS will fail to adapt and symptoms will not decrease.

**Elimination of Visual Dependence**

When the use of vestibular inputs has been minimized through self-limitation of head and eye movements to control dizziness and imbalance, the visual system often becomes dominant for balance. Testing as identified in Figure 22-34 can be used for intervention. Another way to train the client to use vestibular input versus vision is watching a ball being tossed from hand to hand while standing on a compliant surface (Figure 22-37). This can also be done while walking. Clients with visual dependency often report excessive fatigue because of the strain of using vision for postural stability. When these clients are in situations with excessive visual stimulation, reports of dizziness increase. The subtle eye movements associated with viewing a computer monitor cause more fatigue for the individual with vestibular disorder. These individuals also often avoid crowds as in a mall, grocery store, or airport. Attending church services, which are often characterized by low lighting, visual stimulation, and the need to stand with eyes closed or read a hymnal while singing challenges the vestibular system. Figure 22-38 shows the use of optokinetic stimulus to decrease visual dependence and to improve the ability to maintain gaze reference when there is movement in the visual background.

**Gait**

Gait with head motion is important for the individual with vestibular dysfunction. Because head movement causes visual disturbances and dizziness, the client with a vestibular disorder will significantly limit head movement while walking. When visual cues are used predominantly for balance, the client will try to keep the body in line with vertical and horizontal visual targets. This will decrease the natural movements typically made during the gait cycle. Patients with potentially recoverable vestibular function should be trained to walk with eye and head movements, trunk rotation, and arm swing. Figure 22-39 shows abnormal placement of the foot for stability when the individual is unable to use the head orientation to gravity as the primary reference.

When the vestibular system does not accurately inform the client about the speed and direction of head movement, visual cues are used to determine movement speed and direction in relation to nonmoving objects. However, in environments with a lot of motion, or when someone approaches in the opposite direction, determining speed and direction of self-movement becomes more difficult. Clients often report dizziness and imbalance in a crowd. Changing visual environments can trigger imbalance in the client with visual dependency. Walking into a darkened room, especially if the surface is uneven (as in a theater), can often trigger a fall or stumble. Clients with permanent vestibular loss should be educated about these potentially high-risk environments and taught compensatory strategies to ensure safe mobility. If improvement in vestibular function is anticipated, however, then progressive exposure to these busy environments is needed to prepare the client for real-world mobility.

To increase somatosensory input, clients with a vestibular disorder often put the whole foot down at once to get better input on the position of the body relative to the ground. The normal heel-toe weight progression over the ball of the foot...
is diminished. This is often seen in conjunction with increased step width while walking. This compensatory strategy is acceptable in clients with permanent loss but should be discouraged in clients who do not need to be overreliant on somatosensation for balance control during walking. Walking on uneven surfaces can be a challenge if the client is primarily reliant on somatosensory input and has poor visual-vestibular interaction. This is one reason why walking indoors is less of a problem than walking outdoors. Again, clients who are not expected to recover vestibular function should be educated about these potentially hazardous environments and encouraged to develop compensatory mechanisms to permit safe mobility. Gait training on progressively less stable surfaces is appropriate for clients who need to reduce dependence on somatosensory cues and improve visual-vestibular interaction.

Substitution

Permanent bilateral vestibular loss, however, requires substitution of somatosensation and vision to orient to the environment. Use of a cane or walking stick to increase use of somatosensation and allow more time to prepare for the next step can increase confidence in gait. Control of turns can be achieved by a quick stop while the head is turning, rapid saccade to stable target, and then completion of the turn with a fixed gaze. Figure 22-40 shows the sequence of the spot turn. This process can become second nature and can be performed on a regular basis to increase stability during daily tasks.\textsuperscript{170} Driving can be trained in a safe manner in reference to head turns and visual references by doing a slow blink to decrease distracting visual flow.\textsuperscript{171}

Maladaptation

Clinical interactions have an important influence on the course of maladapted responses. Explaining the psychosomatic connections in detail can be the first step in recovery. This is critical in order to engage the patient who demonstrates strong avoidance behaviors. Successful outcomes are possible; however, the process may take longer because the central modulation of sensory input is compromised, and therefore adaptation will occur in smaller increments. Proper referral to someone to assist with the management of the psychological or psychiatric condition should always be considered.

Figure 22-39 ■ A and B, When the vestibular, visual, and somatosensory systems are integrated properly, the movement of the head does not change the pattern of the step. C and D, When the vestibular system is not primary for reference, step outs occur during head rotations. This demonstrates the foot moving in the direction of head turn, causing a staggering gait pattern seen often with patients with lack of ability to activate primary dominance of the vestibular system. (Courtesy Ray Hedenberg, IRB Solutions, Silverthorne, Colo.)

Figure 22-40 ■ The “spot turn” for the patient with bilateral vestibular loss. A, When the patient is ready to turn, the front foot is planted to provide somatosensory reference. B, Once the foot is planted, the head is turned. C, Visual reference on a nonmoving target is maintained while the body turns under a stable head. (Courtesy Ray Hedenberg, IRB Solutions, Silverthorne, Colo.)
FEEDBACK

Biofeedback can be used in a variety of ways. Feedback about correct postural responses remains the task of the therapist in the training paradigm. Visual feedback has been used to supplement center of pressure reference for control of weight shifting using vision to supplement vestibular integration to somatosensory inputs. Visual feedback about the head and trunk movement versus total movement on a perturbed surface is available on the Proprio 5000 (Figure 22-41).

Use of the Nintendo Wii Fit has been popular and provides information about results of weight shifting integrated into games that integrate a balance task into an activity that may represent another activity. Training is performed on a nonmoving surface, so somatosensory drive is activated. Patients with visual motion hypersensitivities may find the games overstimulating at the beginning of the session, but playing them may also be an appropriate method to increase adaptation so that more visual stimulus can be tolerated.

Audio feedback has long been used in the patient with vestibular system loss to provide information about sway when surface and visual reference is lacking. It can be used in many different ways for intervention.

Vibrotactile feedback using accelerometer or gyroscopic information has emerged in recent years. This has been successful on many levels, and the modes of input are becoming less intrusive to those who wear them. The input typically provides immediate positive changes in performance of a task, with behaviors that represent improved postural response to gravity reference; however, the rate of retention or carryover may still be related to available plasticity within each system.

CONCLUSION

This chapter has been divided into two sections owing to the specificity and amount of information specific to both areas. Balance was presented first because of the general nature of this topic and because it lays the foundation for discussion of vestibular problems. Although vestibular disorders have a direct effect on balance, not all balance dysfunction is caused by vestibular problems. With the amount of research available in both areas and the areas of specialization separating, the chapter was separated to aid the readers in focusing on specific problem areas. The references have been placed chronologically as appearing in the chapter, but the reader will see that the two portions have been clearly identified to assist in finding materials specific to the topic of interest. The complexity of these two topic areas has grown as new research and new technology have become available. Outcomes of treatment once thought unrealistic have become reality. Many patients who once thought their quality of life was permanently diminished and their ability to participate in meaningful activities had been taken away now show tremendous improvement in functional movement. The effectiveness of therapists working with these patients depends on understanding the specificity of the clinical problems and applying interventions that show measurable change. The importance of active patient participation cannot be overemphasized when discussing motor control and motor learning principles needed to optimize positive changes in balance and in specific vestibular disorders. These problems dramatically affect an individual’s quality of life, and the role occupational and physical therapists play in providing appropriate interventions has established efficacy in practice.

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References

To enhance this text and add value for the reader, all references are included on the companion Evolve site that accompanies this textbook. This online service will, when available, provide a link for the reader to a Medline abstract for the article cited. There are 182 cited references and other general references for this chapter, with the majority of those articles being evidence-based citations.
CASE STUDY 22-1  ■ ANDY

Andy is a 27-year-old man who sustained a severe closed-head injury in a skiing accident. He was hospitalized for 2 months and resided at a long-term care facility for 6 months before cranial surgery for removal of bilateral subdural hygromas and revision of a ventriculoperitoneal shunt. After surgery he demonstrated marked improvement and was transferred to a rehabilitation unit. His initial physical therapy assessment revealed the following impairments, which had a negative effect on postural control:

1. Oculomotor deficits (difficulty tracking to the right and upward)
2. Disorientation
3. Delayed and slow motor responses
4. Bilateral ankle plantarflexion contractures (1 to 10 degrees left, 1 to 15 degrees right); limited right shoulder flexion (0 to 100 degrees) and external rotation (0 to 20 degrees)
5. Hypotonic trunk (right, moderate; left, mild), hypertonic (extensor) lower extremities (right, moderate; left, mild), hypertonic right upper extremity (mild)
6. Fair head control
7. Poor trunk control with right scapular atrophy, shortened right side, strength 3–5
8. Left upper and lower extremity movement isolated and coordinated but slow, strength 4/5 at shoulder, 4+5 elbow, wrist, hand, 4/5 hip and knee, 3+5 ankle, able to place and hold for weight bearing
9. Right upper extremity rests and moves in synergistic pattern but can move out of synergy with request or demonstration; strength 3–5 at shoulder and 4–5 distally; coordination is poor; can place and hold for weight bearing if cued but not spontaneously
10. Right lower extremity moves in flexor-extensor pattern, grossly 3+5/4 hip and knee flexion, 2+ hip extension, 3+5 knee extension, no isolated ankle movement, cannot place or hold for weight bearing

Functional tests found the following activity limitations:
1. Minimum assist supine-to-sit
2. Sitting balance, poor
3. Moderate assist sit-to-stand
4. Standing balance, unable
5. Moderate assist transfers
6. Nonambulatory

Body system impairment goals were the following:
1. Increase ROM to within normal limits throughout
2. Increase trunk tone to normal and strength to 4+5
3. Decrease right-sided tone to normal
4. Increase spontaneous use, isolated movement, and strength (4+5) in right extremities
5. Able to place and bear weight on right lower extremity

Short-term functional goals were the following:
1. Independent in all bed mobility
2. Independent in wheelchair transfers
3. Good static and fair dynamic sitting balance
4. Contact guard sit-to-stand
5. Minimal assist static standing balance

Note: Ambulation goals were temporarily deferred because of the ankle contractures and balance deficits.

Early treatments included the following:
1. Standing frame activities for head control, visual tracking, trunk control, reduced lower-extremity extensor tone, and heel cord stretching with ultrasound
2. Neurodevelopmental sequence activities for head and trunk control; trunk strengthening; decreased lower-extremity extensor tone; balance on all fours, heel sitting, kneeling
3. Supine to and from sitting, especially over the right arm
4. Sitting balance with upper-extremity functional tasks (e.g., putting glasses on and taking them off, taking shirt off and putting it on, wiping nose with tissue), with focus on right visual tracking, right trunk elongation, and incorporation of right lower-extremity ground pressure for stability
5. Transfer training with incorporation of right upper extremity to push up, reach and grasp, and right lower-extremity placing and weight bearing

As soon as Andy’s ankle dorsiflexion ROM was near neutral on the right (was then 0 to 5 degrees on the left), neurodevelopmental activities were phased out and standing balance and pregait activities in the parallel bars were initiated with moderate assistance. He rapidly progressed to minimal-assistance gait in the parallel bars but with significant scissoring of the lower extremities. Gait outside the bars was begun with a quad cane on the left, but Andy was not able to organize the sequence for cane use and did not use the cane when loss of balance occurred, so use of the cane was discontinued. Gait without an assistive device required moderate assistance from the therapist for balance. A line drawn on the floor provided a visual cue to remind him to keep his feet apart when walking without this cue, approximately 25% of his steps were close or crossed.

At discharge, 2 months after admission, Andy had good visual tracking; normal ROM with the exception of right lower-extremity dorsiflexion, which was limited to 0 to 5 degrees; normal tone in the left extremities; mildly increased tone in the right extremities with slight extensor patterning in the leg; good head and trunk control; and strength grossly 4+5 throughout. Functionally, he was independent in bed mobility, wheelchair mobility, and sitting balance. He required supervision for safety in transfers and standing activities and minimal to moderate assistance for indoor ambulation without an assistive device depending on his fatigue level.
Doris is a 73-year-old woman with a long history of Parkinson disease who had fallen four times within the 6 months before referral to physical therapy. As a result of her most recent fall, during which she hit her head, Doris had ear pounding, light-headedness, and headaches. After referral to an otolaryngologist, she was diagnosed with unspecified peripheral vestibular dysfunction and referred to outpatient therapy. Her therapist found that Doris reported increased lightheadedness and dizziness, with anterior-posterior head movements, rolling in bed, sit-to-stand, and the Hallpike-Dix maneuver (worse to the right). Multiple impairments that could be contributing to her instability and falls, as well as symptoms related to the vestibular disorder, were also noted. Doris had mildly decreased ROM in her left ankle, shoulders, and neck; mild left-sided weakness and lack of coordination; marked bilateral upper-extremity tremor; and moderately forward-flexed posture.

She could not perform an ankle strategy at all and continually used hip strategy; she also used stepping strategy frequently with the least shift or sway. Static postural sway tests indicated that Doris had excessive sway when attempting to stand still and that she kept her COG slightly posterior and to the right of midline. Sway increased tenfold with eyes closed, indicating poor use of somatosensory inputs for postural control. Doris could not perform repeated weight shifts in either anterior-posterior or medial-lateral directions. Her limits of stability were severely restricted to less than half of normal sway range anteriorly, and her movement time was slow.

Functional testing revealed that Doris had several disabilities. She had to use a walker or have manual assistance to ambulate and could negotiate level surfaces only. Without her walker or handhold assistance, Doris could stand for less than 30 seconds and take a maximum of 10 steps. For community ambulation, Doris needed minimum assistance with her walker and could go only short distances. She also required minimum assistance with bathing and household tasks.

Doris participated in therapy twice a week for 6 weeks and also performed a home exercise program daily. Her treatment plan included vestibular exercises for the dizziness and balance retraining exercises for instability and falls. The vestibular exercises she was given were designed to provoke her symptoms repeatedly and included head turning in supine and sitting (progressed to standing), rolling in bed, rocking in a rocking chair, and sit-to-stand practice. As her dizziness subsided, her home program was modified to increase the number and rate of head movements. To improve her use of somatosensory and vestibular inputs, Doris also practiced standing on a firm surface with eyes closed (with family supervision). In the clinic, Doris did stretching, strengthening, and postural extension exercises to address her musculoskeletal limitations. For increased use of somatosensory and vestibular inputs, she practiced standing and weight shifts with optokinetic stimulation. By using postural sway biofeedback, she practiced achieving the midline position, controlled anterior and left-sided weight shifts at progressively faster speeds, and ankle strategy. Gait training included starts, stops, turns, and obstacle avoidance and progressed to community ambulation tasks such as curbs and ramps. As her endurance improved, she also did gait training on the treadmill to increase the gait speed, stride length, hip strength, and use of vestibular inputs.

Despite her multiple problems, Doris was able to reduce the severity of her impairments and consequently improve her functional level. Her dizziness resolved completely. Although she still had excess sway during static standing, she was able to achieve and hold a midline position, and her sway with eyes closed reduced by more than half. Doris could shift her weight in both anterior-posterior and medial-lateral directions at moderate speeds by using ankle strategy without stepping. Her limits of stability were expanded from 35% to 80% of normal, and she was able to shift her weight much more quickly. Functionally, she could stand without the walker for 8 minutes and walk independently indoors on level surfaces without the walker for short distances. She was independent in community ambulation with the walker. At a 3-month follow-up visit, Doris reported that she had experienced no more falls.
APPENDIX 22-A ■ Common Vestibular Disorders

Benign Positional Vertigo (BPV)
The otoconia in the otolith can become loose, clump together, and form densities known as canaliths, which can move into a semicircular canal and become a cause of vertigo. In cases of BPV, the involved side is distinguished by which ear is toward the ground when the symptoms occur. The critical hallmark of BPV is that the vertigo usually starts after 5 to 10 seconds and resolves or fatigues within 20 to 40 seconds. A less common variant of BPV, cupulolithiasis reflects the adherence of the otoconia to the cupula. The vertigo associated with change of head position is caused by the direct pressure deflection of the cupula. The vertigo appears with less latency and is often more persistent, taking up to 60 seconds to resolve after change of head position.

Benign positional nystagmus or vertigo is a common sequela of head concussion, viral labyrinthitis, hydrops, and vascular occlusion in the distribution that feeds the inner ear. It can also develop without a known external cause and is the most common cause of vertigo. Other conditions that can cause head position dizziness are described in Appendix Box 22-1.

BPV may involve any semicircular canal, although the posterior canal is most common because of its relationship to the otoliths when the person is in the recumbent position. The horizontal canal can also collect otoconia, and the result is horizontal nystagmus generated with head movement; dizziness often occurs as the head is going backward, when the horizontal canal moves into the gravity-responsive position. The dizziness is also triggered in the head rotated and flexed position.

Despite the use of the term benign, the symptoms related to positional vertigo are intense and can cause significant disability. There is often a strong sense of falling or spinning out of control, even when the individual is lying on a bed. Before the individual is aware of the mechanism, it seems to be something that is uncontrollable because it is associated with head movement. Spontaneous remissions are common and may reflect an underlying disorder such as hydrops or migraine-induced ischemia. Infections or inflammations may occur months or years before the onset of BPV. Adverse life events are reported to trigger an event, especially in individuals with an underlying disorder.

Infection
Acute unilateral vestibulopathy affects the vestibular nerve. Most often the infection is viral in nature and is known as neuronitis or neuritis. It can also be caused by bacterial infection from a variety of causes, either as a primary infection or secondary to bacterial meningitis or encephalitis. Vestibular neuritis can be partial, affecting the superior afferents from the horizontal and anterior semicircular canals primarily.

The infection often is preceded by a systemic illness or an upper respiratory tract infection, but it can be an isolated infection affecting the nerve or labyrinths. This causes an acute, severe dizziness often accompanied by nausea and vomiting. Initial impairment may include nystagmus; the individual has normal balance and form densities known as canaliths, which can move into a semicircular canal and become a cause of vertigo. In cases of BPV, the involved side is distinguished by which ear is toward the ground when the symptoms occur. The critical hallmark of BPV is that the vertigo usually starts after 5 to 10 seconds and resolves or fatigues within 20 to 40 seconds. A less common variant of BPV, cupulolithiasis reflects the adherence of the otoconia to the cupula. The vertigo associated with change of head position is caused by the direct pressure deflection of the cupula. The vertigo appears with less latency and is often more persistent, taking up to 60 seconds to resolve after change of head position.

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APPENDIX BOX 22-1 ■ ALTERNATIVE CAUSES OF HEAD POSITION DIZZINESS AND NATURE OF DIZZINESS

Unilateral vestibular dysfunction: Dizziness when changing head position while supine

Vestibular migraine: Episodic dizziness that can usually be related to specific triggers

Cerebellar nodulus: Nystagmus, downbeat without torsion without fatigue or habituation

Vertebral artery compression: Nystagmus with extreme rotation or extension of neck

Central vestibular pathways: Nystagmus without dizziness, usually unidirectional

Geriatric supine nystagmus: Vertical nystagmus when supine

Perilymph fistula: Episodic dizziness after trauma, increases with Valsalva or head hanging

Superior canal dehiscence: Dizziness with loud noises or change of head position

Hypermobile stapes: Unstable at oval window; allows fluid pressure changes that cause dizziness with head positions

Head extension: Otoliths outside of functional range, causing dizziness

Orthostatic intolerance: Dizziness when bending or quickly standing from sitting, never when lying
APPENDIX 22-A  ■  Common Vestibular Disorders—cont’d

Persistent sense of dizziness that is relieved by recumbent positions with minimal head movement. Typical vestibular testing is nondiagnostic, but use of pressure in the ear may assist this diagnosis. Vestibular rehabilitation for adaptation fails because the system has a persistent fluctuating nature. Successful surgical repair of the fistula produces the stability needed to resume rehabilitation efforts.

Superior Semicircular Canal Dehiscence Syndrome
Dehiscence or thinning of the bone overlying the superior (anterior) semicircular canal creates a “third mobile window,” and the effect of change in pressure of the canals appears to be similar to the fistula. Loud noise or pressure can cause disequilibrium. Surgical repair usually produces good results.

Vertiginous or Vestibular Migraine
The aura or even the primary symptom of migraine may be dizziness. Diagnosis is based on the episodic nature, recognition of triggers, history of migraine, and combination of dizziness with the other typical prodromes of migraine including photophobia, nausea, and vestibulocochlear symptoms of tinnitus and sensitivity to sound. The pathophysiology follows that of migraine headache, in which there are multiple levels of dysfunction from gene defects that drive familial autosomal disorders and an inherited migraine threshold, brain stem activity that can trigger vascular responses of dilation or restriction, serotonin platelet activity, and spreading neuronal depression. Medical management follows the criteria for migraine. Rehabilitation is indicated when avoidance of activity has changed the sensory integration, or when multiple episodes have influenced the system toward dependency or hypersensitivity patterns.

Vascular Disorders
Ischemia in the areas of the vestibular system (brain stem, cerebellum, parietal-insular cortex) can cause dizziness and imbalance. Vertebral basilar artery insufficiency syndrome, for example, classically produces these problems. Ischemia is usually seen in individuals older than 50 years, but it can also be associated with bleeding disorders such as leukemia. Migraine headache can cause intermittent dizziness from compromise of blood flow in the areas of the vestibular system.

Neoplasia
Neoplasia can compromise vestibular function when it occurs near any part of the vestibular system. Vestibular schwannoma (commonly but mistakenly known as acoustic neuroma) can cause damage as it slowly grows on the sheath of the vestibular nerve. The schwannoma can grow into the pontocerebellar angle and cause symptoms typically associated with cerebellar lesions. Meningiomas (encapsulated tumors found most often deep in the brain) growing in the area of the temporal lobe can cause pressure on the vestibular mechanism. In some cases, damage to the vestibular nerve occurs as a result of surgical removal of the tumor.

Otoxicity
Aminoglycosides, antibiotics used in cases of massive or systemic infection, can be ototoxic (causing damage to the vestibular hair cells). Although a small percentage of users experience this adverse effect, it can affect both sides of the bilateral vestibular apparatus and cause significant disability. Often the client does not begin to experience the symptoms until the medication has been used for more than a week.

Traumatic Brain Injury (TBI)
TBI can affect the vestibular system in several ways. It can cause direct damage to the vestibular end organ (in the temporal bone); BPV; and, in many cases, disruption of the integration of the vestibular nuclei (in the brain stem) and cerebellum. Sensorimotor disturbances are common with TBI involving the cerebellum or parietal lobe. Visual dysfunction results from damage to brain stem areas such as the pontine gaze centers or central damage in the medial longitudinal fasciculus. Frequently the third, fourth, or sixth cranial nerve is damaged, and this affects the ability to move the eyes for conjugate gaze. In some extensive TBI cases the brain loses its ability to use any of the three sensory systems accurately. Dizziness and imbalance are prevalent complaints from client with TBI because there are often situations in which they cannot acquire accurate sensory information.

Each system should be evaluated individually for its function. In patients with TBI, the adaptation of the vestibular system occurs more slowly and with more effort than in other clients with vestibular deficits. The client with vestibular problems associated with TBI requires significantly more intervention initially, and the outcomes are less favorable than for other clients experiencing vestibular dysfunction.

Allergies
Persons with allergies are often predisposed to episodes of dizziness. Foods, airborne allergens, and chemicals can trigger dizziness in these individuals.

Metabolic Disorders
Vertigo and dizziness are often reported with metabolic disorders such as diabetes. Autoimmune diseases such as rheumatoid arthritis, lupus, and human immunodeficiency virus infection can also cause symptoms when the disease process damages components of the vestibular system.

Autoimmune Ear Disease
Autoimmune responses may result in rapid decline of hearing with intermittent symptoms of vertigo, aural pressure, and tinnitus. It is caused by the deposition of antibody-antigen complex in the cul-de-sacs or basement membranes of inner ear structures. It can appear in the same manner as hydrops, with fluctuations of hearing loss and vestibular function. The Western Blot is one of the most widely used diagnostic tools.

Autonomic Related Vertigo
The autonomic and vestibular systems are physiologically connected, and significant activation of the vestibular system will cause nausea, pallor, sweating, and clamminess. Autonomic dysfunction can contribute to dizziness and is reported in conjunction with palpitations, chronic fatigue, sleeping disorders, cold extremities, headaches, gastrointestinal disorders, medication intolerance, and fainting.

Mitral valve prolapse can be found in patients with such signs and symptoms, and disorders of circulation should be considered. Orthostatic concerns should be considered, and often patients are found to have abnormal tilt-table test results. Often patients will have been diagnosed with Meniere disease but do not respond to diuretics and, when observed carefully, have signs as described previously, with lightheadedness a component of the dizziness, along with vertigo.
Mal de Debarquement (Disembarkment Syndrome)
The symptoms of continued rocking or a sensation that one has just
gotten off a boat is the hallmark of disembarkment syndrome. In-
deed it comes often after a long boat or airplane ride, often when
there is turbulence. The vestibular system seems to be activated to
a high degree, then is unable to calibrate back to normal in refer-
cence to the somatosensory input available.  

The sensation is greater when the patient is at rest, and move-
ment is actually preferable to standing or sitting. The system re-
 mains maladapted, and the condition can persist over months and
years, causing significant disability and frustration. Rehabilitation
is directed toward recalibration of the somatosensory and vestibu-
lar systems.

Somatoform Dizziness
Forty percent of dizzy patients have psychological disorders, and
individuals with psychological disorders report more disability re-
lated to dizziness. There are connections between the locus coeru-
leus and lateral vestibular nucleus within the brain stem, and both
nuclei are affected by serotonergic processes. Primary somatoform
disorders, dissociative (conversion) disorders, and anxiety disor-
ders produce dizziness without organic cause. Secondary, reac-
tive, or comorbid disorders can emerge as a consequence of identi-
fiable organic dysfunction, but the recovery process is derailed
owing to an underlying psychiatric disorder. Vestibular disorders
have an influence on autonomic regulation, and symptoms such as
heart palpitations, fainting spells, and chronic fatigue are reported
to a higher degree when there is an additional psychogenic compo-
nent. Vertiginous migraineurs have a higher frequency of comorbid
anxiety disorders. The common neuroanatomic pathways provide
focus for interventions. Antivertiginous medications are not effec-
tive, and challenging the vestibular pathways can often lead to in-
creased avoidance behaviors, more dizziness, and actual decline in
function. Determination that there is a psychogenic or somato-
form component of the disorder is often made late in the diagnosis
when treatment from the ear, nose, and throat specialist, neurolo-
gist, or internist has failed. Appendix Box 22-2 describes the
relationship of the disorders.

APPENDIX BOX 22-2 ■ RELATIONSHIP BETWEEN
OTOLOGICAL CONDITIONS AND ANXIETY

Otogenic: Primary otological conditions that can trigger secondary
anxiety disorders
Psychogenic: Anxiety disorders as primary cause of dizziness
Interactive: Otological conditions that exacerbate preexisting
anxiety