Concepts and Methods for Assessing Postural Instability

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Current research suggests that there are complex interactions between intrinsic factors related to the individual and extrinsic environmental factors, all of which contribute to falls in the older adult. A new approach to balance assessment, the task-oriented conceptual framework for clinical intervention, takes into account many of these intrinsic and extrinsic variables in assessing balance function. It contains three levels of assessment of balance and gait function: performance-based functional assessment, strategy assessment, and impairment assessment. This approach quantifies performance on functional tests of balance, determines the strategies used by the individual to carry out functional tasks, and evaluates the relative contribution of specific neural and musculoskeletal variables to normal postural control. Results of recent experiments suggest that older adults who are given a sensory training program that is designed to improve the organization of sensory inputs contributing to balance control (strategy level) are able to significantly improve sway and that this training effect transfers to other balance conditions.

Key Words: aging, balance, training, assessment, treatment

Falls are a serious problem for older adults, with statistics showing that about one-third of the population of community-dwelling older adults fall each year. In addition, in acute care hospitals, falls account for up to 40% of adverse incidents, with older patients experiencing the vast majority of fall-related problems. The incidence of falls increases with age, with the highest incidence of falls in clinical settings occurring in the 80- to 89-year-old group (Tideiksaar, 1995).

Problems in balance control are often a major factor contributing to this high probability of falls in older adults. There is evidence that many older adults who fall have functional balance and walking impairments though they do not have diagnosed neurological or musculoskeletal problems (Studenski, Duncan, & Chandler, 1991). The recognition that balance impairments are a principal contributor to falls in the older adult has resulted in an increased emphasis within the health care community on assessment and treatment of balance to reduce falls in older adults.

Rehabilitation strategies for improving balance in older adults should consider the following issues: (a) current concepts regarding the physiological bases for
normal postural control and age-related effects on the postural control system, (b) the development of clinical and research methods for effectively and efficiently evaluating balance in older adults, and (c) the development of appropriate training programs to maintain high levels of balance abilities in healthy older adults and to improve balance function in older adults with balance control problems (Shumway-Cook & Woollacott, 1995).

**Current Concepts of Balance Control**

Balance may be defined as the ability to maintain the center of body mass (COM) within limits of stability determined largely by the base of support. When the COM is within the stability limits, the body's position can be maintained without changing the base of support. Stability limits are not fixed but are modified according to the body's biomechanics, the task, and features of the environment (e.g., the surface on which the subject is standing). Postural orientation may be defined as the maintenance of efficient relationships between the body parts and between the body and the environment during a given task (Shumway-Cook & Horak, 1993).

**REACTIVE BALANCE CONTROL**

During simple tasks like quietly sitting or standing, the body continually sways; to regulate this sway, the sensory systems continuously process information about the body's position in space. As the COM moves toward a consciously or unconsciously perceived stability limit, a postural response is typically elicited to return the COM to a stable position. This may be referred to as static balance control (Shumway-Cook & Woollacott, 1995).

A more dynamic form of reactive balance control would be the ability to regain stability after an external threat to balance, such as when an older adult is standing on a bus and the bus begins to move forward, causing abrupt backward sway. Thus, reactive balance control is activated by sensory cues reporting movement of the center of mass away from a desired stable position. Muscle responses are activated to rapidly restore the center of mass to a position of stability.

**PROACTIVE BALANCE CONTROL**

Balance control also involves the ability to activate postural adjustments in anticipation of potentially destabilizing situations in order to minimize movement of the center of mass from its desired position. This is referred to as proactive balance control. Older adults would use this type of control when attempting to lift a bag of groceries from a counter. They would need to activate postural muscles in the legs before they pick up the heavy bag, in order to compensate in advance for the shift in the center of mass caused by the voluntary movement.

Stability during complex movements involves both reactive and proactive balance control. For example, during locomotion we use reactive control in response to a slip, trip, or stumble to regain control of the center of mass, while we use proactive balance control to avoid situations that are potentially destabilizing.
AGE-RELATED CHANGES IN BALANCE CONTROL

Research during the last 15 years has shown that balance control is a complex physiological process involving many body subsystems (sensory, motor, cognitive, etc.) and that reflex contributions are only one aspect of that control (Kandel, Schwartz, & Jessell, 1991; Nashner & Woollacott, 1979; Woollacott et al., 1986). A view of postural control stemming from this research has been referred to as a “systems theory” of posture and motor control (Shumway-Cook & Horak, 1990; Shumway-Cook & Woollacott, 1995; Woollacott & Shumway-Cook, 1990). Figure 1 shows this conceptual model for a systems theory, including the interacting systems contributing to balance and orientation. For example, it is clear that motor processing, which consists of both neuromuscular and musculoskeletal components, is important for the generation and coordination of forces involved in the optimal control of the body’s position and forward progression. Sensory processing, including visual, vestibular, and somatosensory components, allows the initial coordination of information regarding the body’s position relative to gravity and the environment. Higher level processes (both cognitive and noncognitive) are also critical for adaptive and anticipatory aspects of balance control. According to systems theory, balance control emerges from interactions among many systems organized in relationship to task and environmental requirements and affordances.

Figure 1. A conceptual model representing the interacting systems contributing to task-specific balance and orientation.
In the next section we will look at the way researchers examine the contributions of different systems to balance control in the older adult, in the context of different task and environmental constraints.

**Motor Systems.** It has been shown that young and older adults use different movement strategies to maintain balance in different contexts and with different task goals. Researchers have explored muscle coordination underlying both reactive and proactive balance control. The most common method used to explore muscle coordination during reactive balance control involves a moving platform to disturb balance in a standing subject.

Figure 2 is a diagram of the experimental apparatus used to examine reactive postural responses and the ability to adapt sensory information for orientation. The platform movements typically used to study reactive balance control are anterior and posterior translations, which cause the older adult to sway in the opposite direction of platform motion, and platform rotations around the axis of the ankle joint, which stretch the distal ankle muscles while producing minimal sway. The size of the base of support may be varied during...

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static or dynamic postural testing in order to determine how subjects adapt their movement patterns to changing task conditions. For example, the subject may be asked to stand on one foot, to stand with feet in the sharpened Romberg position (one foot in front of the other), to stand across a narrow beam, or to stand on a compliant surface. Surface electrodes may be used to record the onset latency, amplitude, and duration of muscle activation patterns in response to platform movements. Motion analysis systems may be used to evaluate the velocity and magnitude of body segment movements associated with recovery of balance and to determine COM displacement, while force plates measure ground reaction forces and compute center of pressure (COP) (Shumway-Cook & Woollacott, 1995).

Results of research involving the above methodology suggest that at least three different types of reactive postural response strategies may be used by young and older adults when regaining stability after a platform movement causing either forward or backward sway: an ankle strategy, a hip strategy, and a stepping strategy (Horak & Nashner, 1986; Nashner & McCollum, 1985; Nashner & Woollacott, 1979). It has been suggested that an ankle strategy is used to compensate for small amounts of sway. For example, when responding to a balance threat causing posterior sway, a young or healthy older adult would correct for the disturbance by anterior sway at the ankle using a muscle response pattern consisting of activation of tibialis anterior (TA), then quadriceps (Q), and then abdominal (A) muscles at latencies of approximately 80, 100, and 120 ms, respectively. Figure 3 gives examples of automatic muscle responses in TA and Q muscles to platform perturbations causing backward sway in young (Y), older nonimpaired (ONI), and older balance-impaired (OI) adults. Note that muscle response latencies in the nonimpaired older adult are significantly slower than those in the young adult, and that those in the older balance-impaired adult show even slower latencies (Woollacott & Moore, 1996). Since monosynaptic reflex onsets would be on the order of 45–50 ms, these responses are considered to involve longer loops that tend to be more adaptable to changes in task and environmental conditions (Nashner & Woollacott, 1979; Shumway-Cook & Woollacott, 1995).

It has been suggested that a strategy involving higher amounts of movement at the hip joint is used to compensate for larger amounts of sway, or faster perturbations to balance, that are still within the limits of stability. Research indicates that a hip strategy is used when a subject stands on a short support surface, which reduces the ability to generate forces at the ankle joint to compensate for sway. When the platform moves backward, the subject bends forward at the hip, activating the abdominal and quadriceps muscles (Horak & Nashner, 1986). Finally, a strategy involving a forward or backward step may be used in response to perturbations that cause subjects to sway beyond their stability limits. A step is then taken in order to regain stability (Shumway-Cook & Woollacott, 1995). Research suggests that many older adults are more likely to use a hip strategy than young adults when responding to threats to balance, even when support surface movements are within the normal range for use of an ankle strategy in young adults. This shift to the use of a hip strategy in some older adults may be due to reduced ankle muscle strength or reduced sensation in the ankle joint, causing a decrease in the ability to generate torque at the ankle joint (Manchester, Woollacott, Zederbauer-Hylton, & Marin, 1989).
Research methods for studying proactive balance control include recording surface electromyograms (EMGs), kinematics, and ground reaction forces as subjects perform a lifting task or a pushing task with the upper extremities (Cordo & Nashner, 1982). In addition, to examine the integration of balance into a complex movement such as walking, one can measure the adaptation of gait patterns (EMGs, kinematics, and ground reaction forces) to both expected (proactive balance control) and unexpected (reactive balance control) obstacles. Research indicates that postural muscle response patterns similar to those activated in reactive postural control are used in proactive postural control in situations where subjects are asked to push or pull on a handle (Cordo & Nashner, 1982). Research suggests that older adults activate postural muscles (specifically, the dorsiflexors of the ankle joint) significantly more slowly than young adults when using them in a proactive manner (Inglis & Woollacott, 1989).

Figure 3. Examples of automatic muscle responses to platform perturbations causing backward sway in young (Y), older nonimpaired (ONI), and older balance-impaired (OI) adults.
Sensory Systems. Knowing the motor patterns that an older adult uses for balance tells the clinician only a part of the story concerning the individual's balance abilities. It is also important to know what sensory information the nervous system is using to determine the body's orientation in space and to determine whether the body is stationary or moving. The central nervous system determines body orientation and motion using inputs from visual, somatosensory (proprioceptive, cutaneous, and joint receptors), and vestibular systems. Each sensory system is used to process different types of orientation information, and thus each system provides a different frame of reference. Since one aspect of balance control is the ability to adapt to changing tasks and conditions, the nervous system must be able to shift from the primary use of one to the use of another of the three main systems as demands shift (Nashner, 1982; Shumway-Cook & Horak, 1986, 1990; Shumway-Cook & Woollacott, 1995).

One method that has been used to examine the role of sensory inputs in balance control involves measuring body sway while the subject stands quietly for 20 s under six different conditions that alter the availability and accuracy of visual and somatosensory inputs for postural orientation. This is referred to as the Sensory Organization Test (Nashner, 1982). The amounts of body sway in each condition are compared, and results are used to determine the ability of a young versus an older adult to organize and select appropriate sensory information for postural control. Research has shown that young adults easily maintain balance under all six sensory conditions, though they show increases in anterior–posterior sway when information from visual and/or somatosensory systems is reduced or distorted, leaving the vestibular system to control balance. This research suggests that sensory inputs from the three systems are organized into sensory strategies for postural control that would ensure selection of the most appropriate combination of senses for the task and the environment in which it is performed. In contrast to young adults, older adults sway significantly more in conditions of reduced or inaccurate sensory information. This can be seen in Figure 4, which shows stability under the six sensory conditions in young (Y) and older (A) adults, comparing the ability to adapt sensory information for postural orientation (Woollacott, Shumway-Cook, & Nashner, 1986).

Assessing Balance in the Clinic

In order to effectively assess balance in the clinic, it is important to use a conceptual framework to organize assessment and treatment strategies into a coherent plan, one that takes into consideration age-related changes in the ability to maintain balance as well as current concepts of normal balance control. A conceptual framework provides the clinician with guidance in answering questions such as, “What should be assessed?” “What should be my treatment goals?” “What strategies will be most effective in achieving my goals?”

A systems-based approach to posture and balance control has led to a new conceptual framework for clinical management of balance dysfunction in the older adult. This has been referred to as a task-oriented approach (Horak, 1991; Shumway-Cook and Woollacott, 1995). This has allowed clinicians to gain a better understanding of both intrinsic factors (involving the individual) and extrinsic factors (environmental) that contribute to falls (Campbell, Borrie, & Spears, 1989;
In the following sections we will discuss a task-oriented conceptual framework for clinical intervention related to assessment and retraining of balance function, which will help the clinician answer these questions (Shumway-Cook & Woollacott, 1995). Methods for the assessment of balance in the elderly will be discussed from both research and clinical perspectives. Classical methods for measuring balance, recently developed approaches, and the advantages and limitations of each will be discussed. In addition, one method of balance retraining will be reviewed.


TRADITIONAL APPROACHES TO ASSESSING BALANCE

In the last 20 years a number of methods have been developed for measuring postural stability. One technique involves the use of a rod attached to the subject’s hips, which connects at the base of support to a potentiometer that measures anteroposterior sway (Nashner & Woollacott, 1979). In addition, sway has been measured at the pelvis with displacement transducers that operate by a pull on a self-recoiling fine wire attached at the sternum and at the side of the pelvis (Fernie, Gryfe, Holliday, & Llewellyn, 1982). Fernie et al. (1982) used the latter technique to measure sway amplitude and velocity during quiet stance in institutionalized elderly subjects. The authors found that sway velocity was significantly greater for subjects who fell one or more times in a year than for those who had not fallen. This indicates that sway velocity is correlated with probability of balance loss.

Another method of measuring stability during quiet stance involves the use of force plates. When this technique is used to study balance in older adults, participants are asked to stand quietly on a force plate, and the excursion of the COP (the location of the net force on the support surface) is calculated and used to infer the degree of stability. Patla, Winter, Frank, Walt, and Prasad (1989) showed that healthy older adults did not differ significantly from young adults in the root mean square (RMS; a measure of variability of sway) or in the power spectrum profile of the COP measured during 30 s of quiet stance. However, the authors noted that when older adults were asked to stand in a tandem stance position, they showed significant increases on all measures tested, compared to younger adults. When subjects were asked to close their eyes, these differences became greater (Patla et al., 1989).

Some methodological issues have been raised concerning the validity of using center of pressure data as the sole way to monitor balance control. For example, subjects can change the relationship of body segments (e.g., bending slightly at the hips) and can change the center of pressure without affecting their stability (Keshner, 1994). It has also been suggested that sway and COP measures do not always show strong correlations with postural deficiencies in daily life (Horak, 1992). For example, some patients with severe neurological deficits such as Parkinson’s disease have normal sway amplitudes during quiet stance (Black, Shupert, Horak, & Nashner, 1988; Horak, Mirka, & Shupert, 1989). Thus, using only one evaluative measure, such as sway or COP, may not always provide a valid indication of balance function.

A second method for assessing balance function in the older adult uses a theoretical framework based on reflexes as the primary component of motor control (Milani-Comparetti & Gidoni, 1967; Sherrington, 1947). Traditional clinical assessment has involved the measurement of tendon reflexes, righting and equilibrium reflexes, and vestibulo-ocular reflexes. It is interesting to note that many of the descriptions of changes associated with aging that have come from this theoretical framework see deterioration in neural function in the older adult as involving the release of primitive reflexes (Paulson & Gottlieb, 1968).

Though it has also been common in the past to take the view that there is a single cause for instability in an individual older adult (e.g., sensory neuropathy or vestibular problems), research during the last 10 years indicates that most falls are caused by multiple physiological and environmental factors. Our own research and clinical approach to posture and balance control in older adults takes the perspective
of a systems theory of motor control, which considers a variety of neural and nonneural subsystems as contributing to balance function.

A TASK-ORIENTED APPROACH TO ASSESSING BALANCE

A task-oriented approach to the clinical assessment of balance combines a systems framework of postural control with current models of disablement that categorize patient problems into levels of dysfunction. The WHO model describes four levels of dysfunction: pathology, impairments, functional disability, and handicap (WHO, 1980). Clinicians typically document the effects of pathology at the impairment and functional disability levels. This model, shown in Figure 5, can be used during assessment to identify and document limitations in an older adult’s functional capacity, such as the ability to walk, stand up, lean over, reach, or transfer. In addition, the clinician documents impairments in sensory, motor, and cognitive systems that constrain those functional abilities. We suggest some modifications to this model to allow a more in-depth understanding of balance and locomotor limitations in older adults. These modifications have been developed as part of a task-oriented conceptual framework for clinical intervention. This framework contains three levels of assessment of balance and gait function: performance-based functional assessment (assessment of the functional disability level), strategy assessment, and impairment assessment.

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**WHO**

Pathology .......... Impairments ............ Disability ............ Handicap

Example:

CVA .......... Force control .......... Reach .......... ADLs
  Tone .......... Walk .......... Self-care
  Coordination .......... Transfers .......... Mobility
  Sensory loss .......... Lift .......... Employment
  Balance

**Task-Oriented Levels of Assessment**

Performance-based


Examples:

Functional Reach Test .......... Movement strategies .......... Visual system
  Sensory strategies .......... Somatosensory system
  CTSIB .......... Tendon vibration

*Figure 5.* The WHO model of disablement and its application to understanding the effects of a cerebral vascular accident at various levels. Also shown is the relationship between the task-oriented model’s levels of assessment and those of the WHO model.
Next we will examine the clinical tools used to assess balance at each of these levels.

**Functional Balance Tests.** Performance-based functional assessment focuses on assessing the first level of performance, that is, functional abilities. The assessment tools help the clinician document an older adult’s level of independence. A number of clinical tests are used to assess functional balance skills in the older adult. Some have been developed as quick screening tools that allow the clinician to determine if an older adult is at risk for falls.

The Get Up and Go Test (Mathias, Nayak, & Isaacs, 1986) is a quick screening tool. The subject is asked to stand up from a chair, walk 3 m, turn around, and return to the chair. Performance is graded using the following scale: 1 = normal, 2 = very slightly abnormal, 3 = mildly abnormal, 4 = moderately abnormal, and 5 = severely abnormal. This test is both reliable and consistent; it predicts that older adults who score 3 or higher have an increased risk for falls (Mathias et al., 1986).

Since the original test was created, a timing component has been included, and the new test is called the Timed Up and Go Test. Data indicate that normal adults who are independent in balance and movement skills finish the test in less than 10 s, individuals independent in basic transfers typically finish the test in less than 20 s, and individuals dependent in activities of daily living and mobility skills tend to require more than 30 s to finish the test. Thus, this tool correlates well with functional capacity as determined by the Barthel Index (Mahoney & Barthel, 1965).

The Functional Reach Test (Duncan, Weiner, Chandler, & Studenski, 1990) assesses the ability to reach as far forward as possible while maintaining stability. In this test the older adult is asked to stand with feet shoulder-width apart, and then, with the arm raised to 90° to the front, reach as far forward as possible. The distance that can be reached is compared to established norms. Research has shown that this test is both reliable and accurate in predicting the probability of falls.

The Tinetti Balance and Mobility Scale was also created to evaluate balance and mobility skills in older adults and to predict the risk for falls (Speechley & Tinetti, 1990; Tinetti, 1986; Tinetti & Ginter 1988). The balance portion of the test evaluates performance on 11 different tasks and grades each item 0, 1, or 2. It is typically used together with the Tinetti Gait Evaluation, and a total score then predicts the risk for falls.

The Mobility Skills Protocol, developed at the Fall Prevention Center at Duke University, also evaluates functional performance on tasks that depend on posture and balance control (Duncan, 1993). The test consists of 12 items that are scored on a scale of 0 to 2. The test has also been tested for reliability and validity and is a good predictor for falls in the elderly.

The Functional Balance Scale was developed by Kathy Berg, a Canadian Physical Therapist (Berg, 1993). This test uses 14 different items, which are rated 0 to 4. The test is reported to have good test–retest and interrater reliability. However, there are no norms published for this test.

Though functional analysis provides useful information concerning the efficiency of an older adult’s balance performance, it has limitations. For example, most tests of this type do not assess functional tasks within changing contexts and thus may miss problems in individuals who can carry out a task in one environmen-
tal context but not in another. For example, if a test only examines an older adult under normal lighting conditions in a clinic, it may not identify the person who has difficulty walking in dim lighting or on uneven surfaces.

Also, this type of test typically does not provide information concerning why an older adult has problems with balance control. Therefore, such a test does not help the clinician determine what to treat, since treatment strategies are often aimed at underlying sensory and motor impairments that constrain performance. In addition, performance-based measures don’t reveal the strategy that the older adult used in performing the balance task.

**Strategy Level of Assessment.** Our second level of assessment examines strategies used in balance control. A key point in assessing balance strategies is to evaluate the flexibility of the patient in adapting the strategy to changing contexts. Why should a clinician assess strategies in performing a task? Previous research has suggested that performance depends on four factors, two of which relate to the strategies the person uses in performing the task (Welford, 1982). The factors include the demands of the task, the capacities that the person brings to the task, the strategies the person uses to meet the demands, and the person’s ability to choose the most efficient strategy for the given task. Thus, the strategies that older adults use relate the demands of the task to their capacity to perform the task. As the capacity of older adults to perform a task declines, they need to be able to use alternative strategies to maintain their performance level.

For example, younger adults typically use ankle sway to compensate for small disturbances to balance, since this is a very effective strategy for regaining stability. However, as a person ages, muscle strength is reduced, as is the ability to detect movement at the ankle joint. So an older adult may compensate for balance disturbances by swaying at the hips instead of at the ankles, since the hips are stronger and their movement is easier to detect than ankle movement. A second example relating to balance and mobility involves stair climbing. Young people are able to climb stairs in a well-balanced manner with no assistive devices. As they get older, and strength and balance deteriorate, they may need to hold onto the rails to maintain their balance and move more slowly to accommodate their weaker leg muscles; thus their performance outcome of climbing the same number of stairs will remain at its original level.

Using motor strategies involves assessing movement strategies used during proactive and reactive balance control. Proactive balance strategies are often assessed during self-initiated movements of the center of mass. Older adults are asked to voluntarily shift their weight forward, backward, and side to side, and the type of movement coordination that the older adult uses to maintain balance is observed. When asked to sway forward without taking a step, an older adult may (a) sway forward primarily at the ankle joint, using an ankle strategy to control center of mass motion, or (b) sway primarily at the hips, which decreases forward displacement of the center of mass (Shumway-Cook & Woollacott, 1995).

Movement strategies used during reactive balance control are also evaluated (Bobath, 1978; Carr & Shephard, 1983; Shumway-Cook & Horak, 1993). The clinician may hold the older adult at the hips and displace the hips slightly forward, backward, and side to side. The normal adult responds to a small perturbation backward or forward by using sway principally about the ankles. The clinician
should observe ankle joint movement to determine if the tibialis anterior muscles are active in both legs. If knee and hip motion is not used during these compensatory ankle movements, the appropriate proximal muscle synergists may have been activated in addition to the tibialis anterior muscles. If the clinician uses a larger displacement, it typically causes greater amounts of hip and trunk movement as the subject attempts to maintain the center of mass within the base of support. If the displacement is big enough to move the center of body mass beyond the stability limits, healthy young adults take a step. These three movement strategies are shown in Figure 6.

In the Tinetti Balance Test is a subtest called The Nudge Test (Tinetti, 1986), which measures the ability of the older adult to regain stability when gently pushed backward. The test requires that the clinician gently push on the older adult’s sternum, displacing the center of mass in the backward direction. The test is performed three times, and scoring is as follows: 2 (if steady), 1 (if the subject staggers but regains balance), and 0 (if the subject begins to fall).

Multijoint coordination may be evaluated in the clinic by a subjective analysis of movement patterns. For example, is there extreme flexion of the knees or trunk or asymmetric movements of the body? However, if the clinician requires information on specific timing or amplitude errors in the activation of synergistic muscles used in balance control, methods such as electromyography or motion analysis are required.
The clinician may also assess the older adult’s postural motor coordination in anticipating possibly destabilizing voluntary movements (postural muscles should be activated prior to the prime mover). For example, the older adult may be asked to lift a heavy object quickly. Normally, a small amount of backward sway may be seen in the subject preceding the lift, indicating activation of anticipatory postural responses in the legs. Older adults who don’t make these adjustments typically show forward instability.

Using sensory strategies involves assessing a patient’s ability to adapt how sensory information is used for postural orientation. Evaluating sensory adaptation enables the clinician to determine if the older adult is primarily dependent on one sense for sway orientation information. The clinician can determine if an older adult is visually dominant or proprioceptively dominant, either of which may be a normal sensory strategy. However, it is critical to determine if the older adult is able to use an alternative sense in situations of intersensory conflict.

A test that allows the clinician to evaluate the ability of older adults to use different sensory strategies involves asking the person to balance under conditions where one or more of the sensory inputs contributing to balance is inappropriate or is reduced, thus requiring the appropriate selection of specific sensory inputs for use in balance function (e.g., standing on foam, standing in poor lighting, etc.). This is similar to the research methods described earlier for measuring sensory abilities. One such tool is shown in Figure 7, the Clinical Test for Sensory Interaction in Balance (CTSIB) (Horak, 1987; Shumway-Cook & Horak, 1986). For this test a 24 in. by 24 in. piece of medium-density Temper foam is used in conjunction with a modified Japanese lantern (vertical stripes are placed inside) that has been cut down the back and attached to a headband. The subject is asked to balance for 30 s under six different sensory conditions (see Figure 7). Sensory information from the visual or proprioceptive systems is eliminated or altered (subjects stand on a normal surface or a foam surface, with eyes open or closed or with vision stabilized by wearing the lantern). Balance performance is tested with feet together and hands on the hips.

It has been shown that young adults maintain balance for 30 s on all six conditions with minimal amounts of body sway. In Conditions 5 and 6 they sway approximately 40% more than in Condition 1. Research studies using the CTSIB have developed the following scoring criteria (Cohen, Blatchly, & Gombash, 1993; Di Fabio & Badke, 1990; Horak, Jones-Ryciewicz, Black, & Shumway-Cook, 1992). One fall, regardless of the condition, is considered to be within a normal range. Two or more falls are considered to indicate difficulties in reorganizing sensory inputs. Older adults and patients who have high amounts of sway or who fall in Conditions 2, 3, and 6 are considered visually dependent, that is, highly dependent on visual information for stability. Those with problems in Conditions 4, 5, and 6 are considered surface dependent; that is, they rely on information from the feet for stability.

It has been found that older adults who show higher sway magnitudes or who fall in Conditions 5 and 6 of the CTSIB show a decreased ability to select vestibular inputs for postural control when relevant visual and somatosensory cues are not present. Older adults who show balance loss in Conditions 3, 4, 5, and 6 may have what is termed a sensory selection problem, that is, an inability to efficiently reorganize sensory information for postural control (Shumway-Cook & Horak, 1992).
Figure 7. The six sensory conditions used in the Clinical Test of Sensory Interaction in Balance (CTSIB), a clinical approach for assessing the organization of sensory information for balance control. Reprinted from Physical Therapy, A. Shumway-Cook and F.B. Horak, “Assessing the Influence of Sensory Interactions on Balance,” 1986, 66, p. 1549, with the permission of the APTA.

Evaluating the Subsystems of Balance Control. The third level of assessment of balance control aims to determine the impairments that constrain the use of specific strategies and thus potentially reduce performance levels. This involves assessing the motor, sensory, and perceptual systems involved in balance control.

Motor systems contributing to postural control may be assessed by evaluating both musculoskeletal and neural subsystems. Musculoskeletal system assessment includes measures of range of motion, strength, body alignment, pain, and muscle tone.
It is important to evaluate motor systems, since musculoskeletal constraints may limit the ways in which an older adult is able to regain balance. For example, an older adult with restricted ankle motion or reduced strength in the ankle muscles may be unable to use an ankle strategy to control upright posture. However, an older adult with musculoskeletal limitations at the hips may have difficulty using the hip strategy.

It is also important to evaluate body alignment, since alignment of the body segments over the base of support contributes to the effort required to support the body against gravity. The clinician may use a plumb line in conjunction with a grid in order to quantify changes in an older adult’s alignment compared to that seen in a young adult. The width of the older adult’s standing base of support may also be measured (e.g., a tape may be used to determine the distance between the medial malleoli). Another method to measure placement of the center of mass during standing involves the use of static force plates to measure characteristics of the center of pressure alignment, or the use of two standard scales to determine weight discrepancy between left and right (Shumway-Cook & Woollacott, 1995).

Evaluating the sensory systems contributing to balance control involves assessing the individual visual, somatosensory, and vestibular systems that contribute to balance function. Assessment of the sensory components includes testing the individual senses important to postural control. Evaluating somatosensation (muscle, joint, touch, and pressure) in the lower extremities is of particular importance. Selected tests used to evaluate somatosensation include light touch, two-point discrimination, extinction test, temperature, pain, position sense, movement sense, stereognosis, and vibration. The visual system is also evaluated, with the clinician noting problems such as glaucoma, cataracts, retinal degeneration, decreased visual acuity, diplopia, and peripheral visual field cuts.

In assessing perceptual systems, two aspects of perception particularly important to postural control are evaluated: stability limits and motion perception. First, the patient’s internal representation of his or her stability limits for both sitting and standing is determined. This can be done by asking the patient to sway voluntarily as far as possible in all directions without falling, while the clinician evaluates the patient’s limits of perceived stability. The clinician notes the degree to which the patient is willing to move his or her center of mass and then makes a subjective judgment regarding whether the patient is moving to the full stability limits (Shumway-Cook & Horak, 1990).

Motion perception may be defined as the conscious sense of whether the body is still or in motion. For example, dizziness may be considered a misperception of motion that happens when sensory inputs are inconsistent in reporting body motion. The Vertigo Positions and Movement Test may be used to evaluate the intensity and duration of dizziness in response to movement or changes in head position while sitting, standing, and walking. The intensity of dizziness is rated by the patient on a scale of 0 to 10. The clinician also notes the duration of symptoms and the presence of nystagmus and nausea, sweating, and pallor (Shumway-Cook & Horak, 1990).

Retraining Balance Control

A task-oriented approach to treating the patient with impaired balance function focuses on treatment strategies designed to achieve the following goals derived from the three levels of assessment: resolve or prevent impairments, develop
effective task-specific strategies, and retrain functional goal-oriented tasks. A critical aspect of retraining functional skills is helping the patient learn to adapt task-specific strategies to changing environmental contexts (Shumway-Cook & Woollacott, 1995).

Experiments from our own laboratory (Hu & Woollacott, 1994a, 1994b) have aimed to determine if older adults could improve their balance using a balance training protocol that focused on the ability to adapt the use of sensory inputs to different environmental contexts (a strategy level intervention). Participants were 65 to 87 years of age and received a 2-week training program with five 1-hr sessions per week. Each session consisted of ten 10-s periods of training in eight different sensory conditions. The first four conditions were (a) eyes open, normal support surface; (b) eyes closed, normal surface; (c) eyes open, head extended backward, normal surface; (d) eyes closed, head extended backward, normal surface. These conditions were then repeated with the subject standing on a foam pad, which reduced sway-related support surface inputs (Conditions 5–8). After a 10-min break, the eight conditions were repeated.

Significant improvements ($p < .006$) were found in the amount of sway of the training group between the first and the last day of training in Conditions 4 through 8. These were the conditions in which subjects stood on a foam support or when they stood on a normal surface with head back and eyes closed.

In order to determine if this training could transfer to other balance tasks, both the training group and a control group of subjects were tested up to 4 weeks after the end of training on other balance tasks (standing on one leg with eyes open/closed). The training group stood on one leg significantly longer than the control group during both the eyes-open and eyes-closed conditions at 1 day, 1 week, and 4 weeks following training. These changes in balance ability were accompanied by specific changes in muscle response characteristics when subjects were asked to balance on a platform that was unexpectedly moved forward or backward. The training group coactivated antagonist muscles along with agonist muscles significantly less often after training than before training when compared with the control group.

The results of these experiments suggest that older adults given a sensory training program in balance control are able to significantly improve sway not only under the training conditions but under other balance conditions as well.

**Summary**

Research suggests that balance decline in many older adults can be prevented or remediated. This requires (a) clinical and research methodology for effectively assessing balance function in older adults and (b) training programs for both reducing balance decline in the elderly and ameliorating balance dysfunction. Traditional approaches to balance evaluation in the older adult often have predicted that balance could be represented by a single measure such as sway, and that one could find a single cause of falls for a given individual. Current research suggests that there are complex interactions between intrinsic factors related to the individual and extrinsic environmental factors, all of which contribute to falls in the older adult.
A new approach to balance assessment is called the task-oriented conceptual framework for clinical intervention. This framework contains three levels of assessment of balance and gait function: performance-based functional assessment, strategy assessment, and impairment assessment. This approach quantifies performance on functional tests of balance, determines the strategies used by the individual to carry out functional tasks, and evaluates the relative contribution of specific neural and musculoskeletal variables to normal postural control. This approach allows the clinician to determine problems at all three levels and therefore design treatments that can improve function at the systems, strategy, and performance levels.

Recent experiments have aimed to determine if older adults could improve their balance using a balance training protocol that focused on the ability to adapt the use of sensory inputs to different environmental contexts. The results of these experiments suggest that older adults given a sensory training program in balance control are able to significantly improve sway and that this training effect transfers to other balance conditions as well.

References


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