Department of Veterans Affairs

JRRD Volume 45, Number 8, 2008
Pages 1215–1226
Journal of Rehabilitation Research & Development

Balance control in hemiparetic stroke patients: Main tools for evaluation

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Abstract—Balance problems in hemiparetic patients after stroke can be caused by different impairments in the physiological systems involved in postural control, including sensory afferents, movement strategies, biomechanical constraints, cognitive processing, and perception of verticality. Balance impairments and disabilities must be appropriately addressed. This article reviews the most common balance abnormalities in hemiparetic patients with stroke and the main tools used to diagnose them.

Key words: balance evaluation, balance scales, balance tests, brain infarct, falls, hemiparesis, postural control, postural stability, posturography, stroke rehabilitation.

INTRODUCTION

Hemiparesis is the most frequent neurological deficit after stroke [1]. Hemiparetic stroke patients frequently present balance abnormalities. Balance impairments increase fall risk, resulting in high economic costs and social problems [2–5]. Tailoring efficient therapeutic approaches depends on appropriate evaluation of specific needs, but the best tools for balance evaluation in patients with stroke are still under debate [6–7].

Difficulties in determining individual causes of balance impairment and disability are related to the diverse mechanisms involved. Decreased muscle strength, range of movement, abnormal muscle tone, motor coordination, sensory organization, cognition, and multisensory integration can contribute to balance disturbances at different levels [8–11]. The aim of this article is to review the main postural abnormalities and the different tools that can be used to evaluate balance in hemiparetic patients with stroke.

BASIC BALANCE CONCEPTS AND ABNORMALITIES IN PATIENTS WITH STROKE

Postural control requires the interaction of many physiological systems. A simplified outline of posture control is shown in **Figure 1**.

Sensory Modalities and Integration

Three sensory modalities are mainly involved in postural control: somatosensory, visual, and vestibular afferents. Integration of information from these systems is crucial for adequate postural control.

Sensory information is regulated dynamically and modified by changes in environmental conditions [12]. Despite the availability of multiple sources of sensory information, in a given situation, the central nervous sys-

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Abbreviations: BS = base of support; CDP = computerized dynamic posturography; CG = center of gravity; CM = center of mass; CNS = central nervous system; CP = center of pressure; ICF = International Classification of Functioning, Disability, and Health; SOT = Sensory Organization Test.

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DOI: 10.1682/JRRD.2007.09.0150

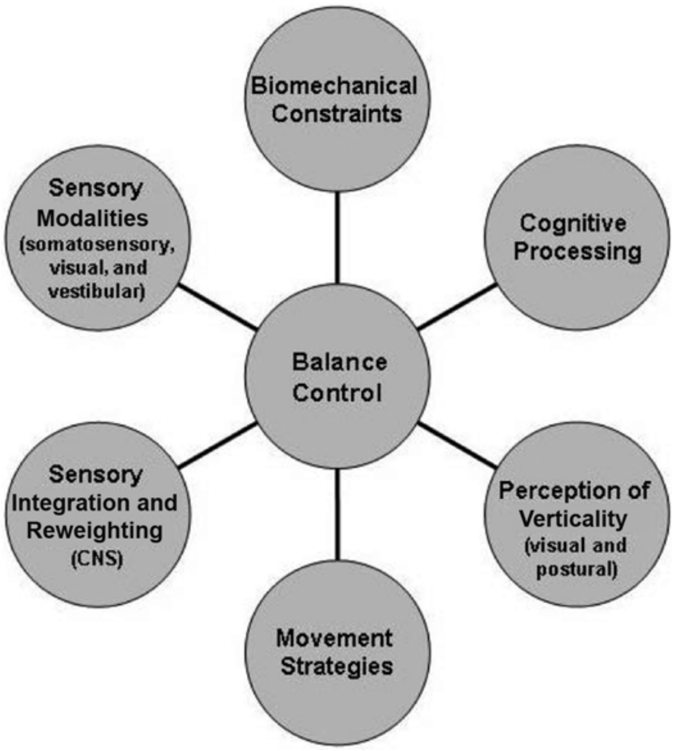

Figure 1.
Important resources required for postural control. CNS = central nervous system.

tem (CNS) gives priority to one system over another to control balance in the orthostatic position [13]. Nondisabled adults tend to use somatosensory information from their feet in contact with the surface while standing in a controlled environment with a firm base of support (BS) [12–14]. Under this condition, somatosensory afferents account for 70 percent of the information required for postural control, while vestibular afferents account for 20 percent and visual input for 10 percent [12]. Visual and vestibular inputs are likely to be more relevant sources of information when proprioceptive information is unreliable, for instance, during sway [12,14–16]. The ability to choose and rely on the appropriate sensory input for each condition is called sensory reweighting [17–18]. When one is standing on an unstable surface, for instance, the CNS increases sensory weighting to vestibular and visual information and decreases the dependence on surface somatosensory inputs for postural orientation. On the other hand, in darkness, balance control depends on somatosensory and vestibular feedback.

Sensory reweighting is also important in the situations of sensory conflict that frequently occur in daily activities; for example, when someone stands next to a bus in movement. In this situation, the visual system reports relative movement of the person in relation to an object, which conflicts with information from the somatosensory and vestibular systems. The CNS must reject visual information and use vestibular and somatosensory inputs. The ability to analyze, compare, and select the pertinent sensory information to prevent falls can be impaired in hemiparetic stroke patients [8].

In patients with stroke, balance impairments and decreased ankle proprioception are positively correlated [19–21]. Abnormal interactions between the three sensory systems involved in balance could be the source of abnormal postural reactions [8,22–23]. In situations of sensory conflict, a patient with stroke can inappropriately depend on one particular system over another [22]. Laboratory measurements of sensory organization demonstrate that patients with chronic stroke perform worse in conditions of altered somatosensory information and visual deprivation or inaccurate visual input [8]. Excessive reliance on visual input may be a learned compensatory response that occurs over time [8]. Relying on a single system can lead to inappropriate adaptations and, hence, balance disturbances. Furthermore, sensory integration and reweighting can be impaired in patients with stroke, emphasizing visual input even when it provides inaccurate information [8,24–25].

Biomechanical Constraints

Postural stability can be understood as the ability to keep the center of gravity (CG) within the limits of the BS, or stability limits; these limits are not fixed, but rather can be modified according to tasks, movements, individual biomechanics, and environmental aspects [17]. Thus, impairments in range of movement, tone, strength, and muscle control can influence postural control. The CNS has an internal representation of stability limits and uses it to determine how to move and maintain balance [18].

The most important biomechanical constraint to balance is the quality and the size of the BS [18]. In hemiparetic patients, weakness and impaired muscle control of the affected lower limb, decreased range of motion, and pain can lead to changes in the BS [11]. The center of pressure (CP) can be displaced anteriorly in the paretic leg because of anteroposterior muscle imbalance in the ankle joint (equinus foot). A positive correlation exists between balance impairments and decreased lower-limb strength [4,19–21,26–27]. In addition, poor trunk control negatively influences overall balance [19,28–29].

Movement Strategies

Studies in the 1980s demonstrated that the human body has postural strategies that are general sensorimotor solutions for postural control and include ankle, hip, and step strategies [30–31]. These strategies involve muscle synergies, movement patterns, joint torques, and contact forces [32]. In the ankle strategy, muscle activation occurs from distal to proximal and the center of mass (CM) is moved with torques mainly in the ankle [33]. In the hip strategy, muscle activation occurs mainly in the hip and trunk, adding torques to the hip joint, knee, and ankle. In the step strategy, muscle activation starts with contraction of hip abductor muscles and with cocontraction in the ankle joint, leading to asymmetric discharge of weight in the lower limbs in order to move the BS during CM movement [31]. The ankle strategy is more effective at keeping the trunk in a vertical position during small perturbations while standing. The hip strategy is excellent for faster and larger CM movements. This strategy requires adequate vestibular information, while the ankle strategy depends more on accurate somatosensory information [32]. The ankle strategy cannot be used properly when the BS is reduced, for instance, on a narrow surface, or when ankle muscle weakness exists [31,34]. During changes in posture, harmonic transitions from the ankle to the hip strategy frequently occur. The step strategy, in turn, represents a completely independent strategy [32], since it adapts the BS to CM movement; in contrast, the other strategies keep the CM inside the BS.

Balance control can be reactive (in response to external forces that displace the CM) or anticipatory (voluntary or in automatic anticipation of internally generated forces during gait or performance of movements, such as raising an arm) [33]. It depends on the capability of the CNS to predict and detect instabilities and program appropriate patterns of muscle activation [32,35]. Delays in postural responses may be caused by a slow increase in muscle activity or changes in spatiotemporal coordination of synergies [32,36].

Patients with stroke use compensatory strategies, including holding objects or walls, and use the step strategy more frequently than do age-matched controls [37]. To maintain the same BS, patients with stroke predominantly use the hip strategy and use the ankle strategy to a lesser extent [5]. However, these strategies are often not efficient for stability [17], as indicated by the high incidence of falls in patients with stroke [2–4].

Although hemiparetic patients can display some anticipatory control in the orthostatic position, their performance is often inferior to age-matched controls. Generation of propulsive forces to initiate displacements of the CM or interruption of these forces so that the CM does not advance beyond the limits of the BS can be inadequate [38]. Patients with mild motor impairments and high functional levels show better anticipatory postural reactions, in spite of abnormal movement activation patterns [39–41].

Cognitive Processing

Motor responses and activation of muscle synergies are influenced by sensory feedback and also by expectation, attention, experience, environmental context, and intention [17]. Greater attentional demands can be required from patients with stroke in tasks of static postural control, particularly as task difficulty increases. Inadequate allocation of attention can lead to increased instability risk and greater fall probability [11,42–43].

Perception of Verticality

Adequate orientation in space is critical for postural control. Nondisabled persons are able to identify gravitational verticality within 0.5° without using visual feedback. Perception of visual verticality is independent of postural verticality. Postural perception of verticality has multiple neural representations [44] and may be abnormal in patients with stroke, particularly in the presence of visuospatial neglect [45–46].

A subset of patients with stroke who have balance problems are distinguished by resistance to support weight on their nonparetic side, a phenomenon historically referred to as “pushing” or “pusher syndrome” [47]. Pushing is clinically characterized as a tendency to adopt postures aligned toward the affected side and a fear of falling toward the nonparalyzed side [48]. Investigation of patients with severe pushing behavior has shown that their perception of body posture in relation to gravity is altered. The patients experience their body as oriented upright when the body actually is tilted to the side of the brain lesion (to the ipsilesional side). Interestingly, patients with pusher syndrome show no disturbed processing of the visual and vestibular inputs determining visual vertical [49].

Influence of Lesion Location

Whether or not lesion side is a key determinant of balance impairment after stroke is still a matter of controversy. In most of the studies, balance disturbances have been found to predominate in lesions involving the right cerebral hemisphere [24,50–53]. Integration of spatial information by the right posterior parietal cortex may explain this finding [51]. However, no difference [8,11] or opposite results [10] with worse scores of static and dynamic balance control in individuals with lesions of the left hemisphere have been described. Definitive conclusions about possible effects of lesion side await further investigations.

Effects of Aging on Balance Control

Stroke incidence and prevalence are greater in older adults [54]. Aging is associated with balance disturbances as a result of functional decline of the three sensory afferent systems [17,55], as well as in strength, range of motion, and the neuromuscular system, with a disruption in the organization of muscle responses characterized by activation of proximal before distal muscles [56]. Older adults, as compared with younger adults, use the hip and step strategies more frequently than the ankle strategy [17,57]. The contribution of vision to balance control increases with advancing age, especially under challenging situations [58].

BALANCE EVALUATION IN STROKE

Understanding physiological systems and their different contributions to balance control allows therapists to systematically evaluate the particular impairment, combination of impairments, and disabilities that affect a patient. Impairments alone cannot describe functional deficits. According to the strategies that can be used to compensate for the impairment, two persons with the same impairment can present different functional levels [18]. Identifying specific impairments and limitations in activities of daily living through clinical and laboratory tools is important. Each hemiparetic patient with stroke can have unique combinations of postural abnormalities [18].

Different methods have been developed to evaluate balance in patients with stroke. Some important factors must be considered. An accurate medical history, including history of falls and medications in use, is crucial. Considering the time since stroke is also important. In the acute and subacute phases, particularly during the first 3 months poststroke [59], physiological changes related to spontaneous recovery of paretic leg muscles can contribute to improvement in balance [7,59]. However, recovery of balance, documented by the absence of enhanced function of paretic leg muscle and other mechanisms and lasting for longer than 3 months, may also be important. Balance gains can be mediated by improved stabilization of the head and trunk, better muscular compensation through the nonaffected leg, improved multisensory integration, and progressive and increased self-confidence [7].

Evaluation approaches can focus on impairments or functional activities and include observational scores (such as clinical scales) and laboratory measurements. Tests based on observational methods can be biased sometimes by subjective judgment [9], but their application is cheaper and easier in clinical practice [60]. Most of the time, laboratory measurements involve force platforms that supply kinetic data of postural reactions [61].

Observational Methods

Clinical tests to evaluate balance have been classified according to the level of postural control required to accomplish the tasks assessed in each test or combination of tests [62]. Static balance tests evaluate patients' ability to keep their CG within the BS in steady stance. Dynamic tests are used to evaluate balance in response to voluntary movement or external perturbations [63]. In functional balance tests, patients have to keep their balance while performing functional tasks of different ranges of difficulty according to the kind of activity demanded, such as rolling, sitting over the side of the bed, supported sitting, sitting to standing, standing in different positions, and walking. The most frequently used evaluation tools are summarized in the **Table**.

The World Health Organization International Classification of Functioning, Disability, and Health (ICF) [64–65] provides a multidimensional framework for health and disability suited to classification of outcome instruments. ICF identifies three primary levels of human functioning. Outcomes may measure different domains of each of three levels: body functions/structure (impairment), activities (refers to the whole person), and participation (formerly referred to as handicap). In the **Table**, ICF levels and domain numbers are given for each test.

Sensory conflicts can be provided by particular observational methods. In the Clinical Test of Sensory Integration and Balance [66], the individual has to maintain

Table.
Properties of balance tests and scales used in stroke population.

Test/Scale	Evaluation	Established Reliability & Validity	Score	Limitations	ICF Level & Domain*
Berg Balance Scale (BBS) [1–6]	14 items requiring subjects to maintain positions or complete movement tasks of varying difficulty: sitting, sit-to-stand & stand-to-sit, transfers, standing unsupported, standing with eyes closed, standing with feet together, reaching forward with outstretched arm, turning to look behind, picking up object from floor, turning 360°, placing alternate foot on stool, one foot forward, & single-limb stance.	Internal consistency: Cronbach α = 0.92–0.98; Interrater reliability: ICC = 0.95–0.98; Intrarater reliability: ICC = 0.97; Test-retest reliability: ICC = 0.98; Validity (r): Barthel Index = 0.8–0.94; Balance subscale of Fugl-Meyer Test = 0.62–0.94.	5-point ordinal scale, range of 0–4 for each item. Total score ranges from 0–56.	Floor & ceiling effects. May have decreased sensitivity in early stages post-stroke among severely affected patients, because scale includes only 1 item relating to balance in sitting position.	Activities (limitations to activity-disability): mobility = changing & maintaining body position (d410–d429).
Timed Get Up & Go Test (TUG) [1,7–11]	Single-item test that requires subject to stand up, walk 3 m, turn back, & sit down again.	Test-retest reliability: ICC = 0.95.	Score = time (s) subject takes to complete test activity.	Large floor effect in frail elderly individuals with cognitive impairment. Addresses relatively few aspects of balance.	Activities (limitations to activity-disability): mobility = changing basic body position (d410) & walking (d450).
Tinetti Balance Test [3, 12–17]: Part of Tinetti Assessment Tool (contains balance & gait sections)	Ordinal scale assessing balance as follows: sitting, sit-to-stand & stand-to-sit, standing, response to challenge, eyes closed, turn in place, turn head, lean back, unilateral stance, reach object from high shelf, & pick up object from floor.	Reliability & validity established only for elderly population Interrater reliability: κ = 0.40–1.0; Validity (r): BBS = 0.91; TUG = 0.75; stride length = 0.62–0.68.	16-point ordinal scale. Total score ranges from 0–24.	Not described for stroke population.	Tinetti Assessment Tool mainly assesses body structure (impairments), but Tinetti Balance Test evaluates activities (limitations to activity-disability): mobility = changing & maintaining body position (d410–d429).
Functional Reach Test (FR) [3,18–20]	Single-item test to detect balance problems in older adults. Subject stands with feet shoulder distance apart & arm raised in 90° of flexion. Subject reaches as far forward as possible while maintaining balance in same base of support. Lateral reach test was developed to evaluate mediolateral postural control.	Within-session reliability: ICC = 0.98; Interrater reliability: ICC = 0.99; Test-retest reliability: ICC = 0.95; Validity (ρ): BBS = 0.7.	Score = distance (cm) that patient can reach forward.	Addresses relatively few aspects of balance. Weak measure of stability limits.	Activities (limitations to activity-disability): changing & maintaining body position (d4106, shifting body's center of gravity).
Balance Subscale of Fugl-Meyer Test (FM-B) [2,21–22]: 1 of 6 FM-B subscales (designed to evaluate impairment after stroke)	7 items, 3 for sitting & 4 for standing: sitting without support, parachute reaction (both sides), standing without support, unilateral stance (both sides).	Interrater reliability: ICC = 0.93.	3-point ordinal scale, items range from 0–2. Total score ranges from 0–14.	Floor & ceiling effects.	Fugl-Meyer Assessment mainly assesses body structure (impairments), but FM-B evaluates mainly activities (limitations to activity-disability): mobility = changing & maintaining body position (d410–d429).

Table. (Continued)
Properties of balance tests and scales used in stroke population.

Test/Scale	Evaluation	Established Reliability & Validity	Score	Limitations	ICF Level & Domain*
Postural Assessment Scale for Stroke Patients (PASS) [2,23]	12 items that grade performance for situations of varying difficulty in maintaining posture: sitting without support, standing with & without support, unilateral stance (both sides); or changing posture: supine to affected side lateral, supine to unaffected side lateral, supine to sitting up on edge of table, sitting on edge of table to supine, sit-to-stand & stand-to-sit, standing, picking up pencil from floor. Developed specifically for patients with stroke.	Internal consistency: Cronbach $\alpha = 0.95$; Interrater reliability: $\kappa = 0.88$; Test-retest reliability: $\kappa = 0.72$; Validity (r): Functional Independence Measure = 0.73.	4-point scale ranging from 0–3. Total score ranges from 0–36.	Not described.	Activities (limitations to activity-disability): mobility = changing & maintaining body position (d410–d429).
Dynamic Gait Index (DGI) [24–25]	8 items: walking, walking while changing speed, walking while turning head horizontally & vertically, walking with pivot turn, walking over & around obstacles & stair climbing (evaluation of dynamic balance).	Interrater reliability: ICC = 0.96; Test-retest reliability: ICC = 0.96; Validity in chronic stroke patients (ρ): BBS = 0.83; ABC = 0.68; TUG = 0.77.	4-point ordinal scale ranging from 0–3. Total score ranges from 0–24.	Can only be applied to population able to walk unassisted, although with assistive device (if necessary).	Activities (limitations to activity-disability): mobility = walking & moving (d450–d469).
Multi-Directional Reach Test (MDRT) [26]	Subjects perform maximal reaches with outstretched arm forward (FR), to right (RR), to left (LR), & leaning backward (BR), with feet flat on floor.	Internal consistency: Cronbach $\alpha = 0.84$; Reliability & validity established only for elderly population; Validity (ICC): FR = 0.942; BR = 0.929; RR = 0.0926; LR = 0.0947.	Score = distance (in. or cm) that patient can reach in each direction.	Not described.	Activities (limitations to activity-disability): changing & maintaining body position (d4106, shifting body's center of gravity).
Activities-Specific Balance Confidence (ABC) Scale [27]	16-item self reported questionnaire that asks subjects to rate their balance confidence in performing everyday activities: walking in different environments, reaching, bending, sweeping floor, getting in or out of car, climbing stairs & ramps, & stepping on or off escalator.	Internal consistency: Cronbach $\alpha = 0.94$; Test-retest reliability: ICC = 0.85; Validity (ρ): BBS = 0.36; gait speed = 0.48.	11-point scale ranging from 0% (no confidence) to 100% (complete confidence). Item scores are summed & averaged to yield mean ABC. Scale score ranging from 0–100.	Not described.	Activities (limitations to activity-disability): mobility = changing & maintaining body position (d410–d429); carrying, moving, & handling objects (d430–d449); walking & moving (d450–d469).

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Table. (Continued)
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*ICF domain (d) numbers shown in parentheses.

ICC = intraclass correlation coefficient; ICF = International Classification of Functioning, Disability, and Health; r = Pearson correlation coefficient; ρ = Spearman rank order correlation coefficient.

upright standing under six conditions. In conditions 1, 2, and 3, subjects stand on a fixed surface with eyes open, with eyes closed, and while wearing a visual dome that restricts their peripheral vision and moves along with their head, respectively. The visual dome leads to sensory conflict. In conditions 4, 5, and 6, the subject stands on foam in order to distort somatosensory information from the support surface and the visual conditions described for conditions 1 through 3 are repeated. Trials in each of the six conditions are timed and the contribution of different sensory modalities can be evaluated. In hemiparetic patients, a positive correlation exists between results of this test and sensory and motor functions [67]. The test approximates the sensory conflict situations provided by the sensory organization part of dynamic posturography. However, lack of quantification of load in each foot, CP excursions, and magnitude of external disturbances are limitations of this method.

Force Platforms and Computerized Dynamic Posturography

Balance problems are frequently masked during simple tasks. Laboratory measures of postural reactions can assess balance control with greater sensitivity than observational methods [32,68]. Postural reactions can be quantified in situations of less stability on force platforms: while keeping the feet together, standing on one leg, or during the Romberg’s maneuver [69–70]. In addition, a sensory modality can be removed or attenuated and the effect of these changes in postural control can be evaluated [71].

Removal of sensory information complicates the estimation of CM dynamics (position and speed) [71] and, thus, increases the average amplitude of body oscillations in nondisabled adults [69,72]. Different systems were developed to challenge balance: platforms that slide and incline and equipment that pulls or pushes body segments. Laboratory tools that quantify very small amounts of postural sway, complex body kinematics, and dynamics enable the therapists to identify specific disordered postural subcomponents [73].

Pressure cells have been incorporated into force platforms to measure oscillations unnoticed by the human eye. Using two platforms of force allows the evaluation of the relative contribution of each leg in balance control [11]. In computerized dynamic posturography (CDP), illustrated in **Figure 2**, analog signals from these devices are sampled and stored for offline processing [74].

CDP was developed by Nashner, and the first commercial version was developed in 1987 [75]. CDP allows manipulation of somatosensory and visual afferent information. In addition, the patient's ability to use and reweight each of the available sensory modalities to control balance can be evaluated [74–76]. Angles of body oscillation can be estimated from vertical projections of the CM [77], and ankle and hip strategies in each of the conditions imposed by the device can be checked [74]. CDP contains three protocols. The Sensory Organization Test (SOT) (NeuroCom International; Clackamas, Oregon), illustrated in **Figure 3**, has the great advantage of objectively measuring postural responses under six different sensory conditions. During SOT, useful information delivered to the patient's eyes, feet, and joints is effectively eliminated through calibrated "sway referencing" of the support surface or visual surround, which tilt to directly follow the patient's anteroposterior body sway. By controlling sensory (visual and proprioceptive) information through sway referencing and/or eyes open/closed conditions, the SOT protocol systematically eliminates relevant visual and/or support surface information and creates situations of sensory conflict. In short, it quantifies either inability to effectively use individual sensory systems or inappropriate adaptive responses. CDP (**Figure 3**) predicts balance control during daily life activities [20].

Figure 2.
Computerized dynamic posturography. *Source*: Photograph reprinted with permission from NeuroCom International (Clackamas, Oregon).

Clinical and laboratory evaluation in hemiparetic patients can show asymmetrical distribution of weight in the lower limbs, with deviation of the CM to the uninvolved side [8–11,24,63,78], difficulty in actively transferring and keeping the CM in the hemiparetic side [63,79], in the lateral and anterior directions [80]; and decreased frontal plane stability; impaired muscle selection [66], with consequent increase in body oscillations during standing [11,24,81–84]. Hemiparetic stroke patients may present difficulties in weight transfer from the affected to the unaffected side [38,80]. During the gait cycle, body weight must be transferred to the affected leg in the swing phase [80]. Asymmetry and difficulty in active redistribution of weight in the orthostatic position are the main contributors to abnormalities in the gait of hemiparetic individuals and influence independence, safety, and performance of activities of daily living [78]. Weight distribution is more symmetrical in patients recovering from mild strokes than in those with more severe lesions [41].

In hemiparetic patients a few weeks after stroke, force platforms can reveal excessive postural oscillations and instability that occur mainly in the frontal plane and are worsened by visual deprivation [11]. These abnormalities may improve over time, reflecting better somatosensory integration, with gradual increase in use of proprioceptive and exteroceptive afferent information of

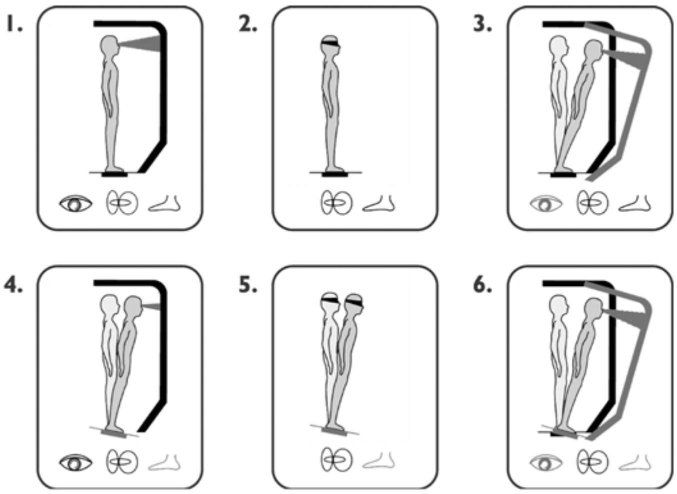

Figure 3.
Sensory Organization Test. *Source*: Figure reprinted with permission from NeuroCom International (Clackamas, Oregon).

the paretic lower limb. However, stability often remains worse than in age- and sex-matched controls. Laboratory measurements show worse scores in dynamic situations in which subjects have to lean in the sagittal and frontal planes: speed is decreased and there are more deviations from the CG [10]. When lateral forces are applied [9], patients with stroke demonstrate larger hip displacements and require more time to restore balance.

Laboratory tools can measure sensory integration in different situations and can quantify body sway and latency of muscle response in each leg after balance perturbations. This information can be used in the first evaluation of the hemiparetic patient and during follow-up to show changes over time [11,41].

CONCLUSIONS

Balance is a complex motor skill that depends on interactions between multiple sensorimotor processes and environmental and functional contexts. Stroke can affect different functions independently or in combination, causing heterogeneous neurological impairments and compensatory strategies. Because of such diversity, individualized rehabilitation is likely to benefit from precise assessment of each patient's impairments in motor, sensory, and cognitive aspects of postural control, as well as the functional implications. Different tools for balance assessment have been validated and should be chosen according to individual characteristics of patients with stroke. Although laboratory measurements are not widely available, they can provide precise information and should be combined with clinical evaluation whenever possible to enhance comprehension of postural impairments and disabilities in hemiparetic stroke patients. Further studies are necessary to investigate whether the use of particular tools of evaluation to guide balance rehabilitation affects function, activity, and participation outcomes.

ACKNOWLEDGMENTS

This material was unfunded at the time of manuscript preparation.

The authors have declared that no competing interests exist.

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Submitted for publication September 19, 2007. Accepted in revised form August 18, 2008.