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## **Evaluation of Postural Stability in Children: Current Theories and Assessment Tools**

Sarah L Westcott, Linda Pax Lowes and Pamela K Richardson  
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## Evaluation of Postural Stability in Children: Current Theories and Assessment Tools

Children with many types of motor dysfunction have problems maintaining postural stability. Because maintenance of postural stability is an integral part of all movements, therapists evaluate and treat to improve postural stability in these children. This article reviews current pediatric assessment tools for postural stability and issues affecting testing this construct in children. The tests and measurements are classified according to their testing purpose and the National Center for Medical Rehabilitation Research disablement framework, focusing on the impairment and functional limitation dimensions. Postural stability is defined from a systems perspective with tests related to the sensory, motor, and biomechanical systems described. Reliability and validity information on the measurements is discussed. Relatively few measurements of postural stability in children are available that have acceptable reliability and validity documentation. Suggestions for research on test development in this area are discussed. [Westcott SL, Lowes LP, Richardson PK. Evaluation of postural stability in children: current theories and assessment tools. *Phys Ther.* 1997;77:629–645.]

**Key Words:** *Balance, Evaluation, Motor dysfunction, Pediatrics, Postural stability, Tests and measurements.*

*Sarah L Westcott*

*Linda Pax Lowes*

*Pamela K Richardson*

**T**o begin a discussion on evaluation of postural stability in children, it is necessary to define the construct. For the purpose of this article, *postural stability* is defined as the ability to maintain or control the center of mass (COM) in relation to the base of support (BOS) to prevent falls and complete desired movements.<sup>1-3</sup> Balancing is the process by which postural stability is maintained. The ability to maintain a posture, such as balancing in a standing or sitting position, is operationally defined as static balance. The ability to maintain postural control during other movements, such as when reaching for an object or walking across a lawn, is operationally defined as dynamic balance. Both static and dynamic postural control are thought to be important and necessary motor abilities.<sup>2,3</sup> Children with many types of disabilities, ranging from learning disabilities with mild motor problems to cerebral palsy with more severe motor problems, have been shown to have dysfunction of postural control.<sup>4-14</sup> These children may exhibit clumsiness and frequent falls during regular daily motor activities or may not be able to maintain a sitting or standing position independently. Physical therapists and occupational therapists have historically placed a high priority on the treatment of patients with postural control problems because this control appears to be an integral part of all motor abilities; therefore, improvements in postural control should lead to improvements in all movements.<sup>1,3</sup>

We will classify the tests and measurements of postural stability that we discuss using three theoretical frameworks, which describe (1) the purpose of an evaluation, (2) the dimension evaluated according to a disablement scheme, and (3) the body systems cooperating to control balance. A brief description of each framework follows.

We believe that there are three primary reasons that therapists assess clients: (1) for discriminative purposes, (2) for predictive purposes, and (3) for evaluative purposes.<sup>15,16</sup> Discriminative tests are designed to determine whether the problem makes the individual different from the typical individual and are used to quickly and easily screen the individual for further diagnostic testing or to test in greater depth to qualify an individual for services. Predictive tests are used to classify people into categories that indicate what their future status will be on the variables tested. Evaluative testing is done to determine change over time or effectiveness of therapy.

The disablement scheme we will use to classify the tests was adopted by the National Center for Medical Rehabilitation Research of the National Institutes of Health.<sup>17</sup> Within this framework, there are defined dimensions for treatment for individuals with disabilities. These dimensions include pathophysiology, impairments, functional limitations, disability, and societal limitations. We will describe tests and measurements from the impairment and functional limitation dimensions only. The purpose of impairment dimension testing is for determination of impairments that are influencing a person's motor ability so that specific relevant therapeutic techniques can be chosen to remediate these problems. Evaluation of the effects of these treatments then needs to follow. We believe that therapists should first examine changes at the impairment dimension because that is one dimension at which treatment should have an effect. Judgments, however, about whether therapy has been effective, in our view, should also be based at the functional limitations dimension. We therefore will present functional tests that have components related to postural stability.

Specific to the construct of postural stability, we will assume a general systems theory of motor control.<sup>1-3,18</sup> According to this theory, there are many systems within the body that work in concert to keep the COM within the BOS when maintaining static postures and to move the COM in relation to the BOS in a controlled manner when engaged in dynamic tasks. The primary systems involved for the process of balancing are (1) the sensory system (visual, cutaneous and proprioceptive [called "somatosensory"], and vestibular senses), which either cues the child that a response needs to be made to maintain control or gives feedback to alter the balance action during a voluntary motor task, (2) the motor system, which creates the movement to maintain posture, and (3) the biomechanical system, which includes the bony and joint frame on which movements are made and the muscles that create the movement torques. Other systems may also play a role in the maintenance of posture<sup>2,3,18</sup>; however, these three systems are primary systems that are within the scope of physical therapists and occupational therapists. The tests and measurements are organized under these system headings.

To be useful, any measurement needs to have adequate reliability and validity.<sup>19,20</sup> For each assessment dis-

SL Westcott, PhD, PT, is Assistant Professor, Allegheny University of the Health Sciences, Broad and Vine Streets, Philadelphia, PA 19102 (USA) (westcotts@allegheny.edu). Address all correspondence to Dr Westcott.

LP Lowes, PhD, PT, PCS, is Assistant Professor, Texas Woman's University, Houston, Tex.

PK Richardson, PhD, OT, is Occupational Therapist, California Children's Services, Santa Barbara, Calif.

cussed, reliability information will be provided. As a general scheme, reliability coefficients can be interpreted as follows: coefficients less than .50 reflect poor reliability, coefficients between .50 and .75 reflect moderate reliability, and coefficients above .75 reflect good reliability.<sup>19</sup> The type of reliability coefficient that was calculated, the type of measurement, and the variability of the data, however, should also be considered in the final determination.<sup>19</sup> Validity of the assessments described will be reported when studies exist. Many times, however, validity has not been examined formally and must then be judged on a face and content level by the therapist. Determination of responsiveness of a test or measurement is one form of validity.<sup>20,21</sup> *Responsivity* describes the ability of the test or measurement to reflect clinically important change when that change has occurred in the individual tested.<sup>20</sup> This ability is very important for evaluative tests and measures. Very little research on the responsiveness of tests has been done.

Before we move to a specific discussion of the available tools for evaluation of postural stability in children, there are several overall recommendations for improving the reliability and validity of measurements. Past experiences of people, their current attention to a task, the actual task being undertaken, and the environment in which the task is being done may influence postural stability.<sup>22-29</sup> Efforts should be taken, especially when using measurements for evaluative purposes, to be aware of, and when possible control, the variables that could affect the measurements.

Awareness of the environmental conditions during specific tests of postural stability could also provide insights for therapy. For example, the type of perturbation is an environmental condition that can affect the balancing response. Balancing can be triggered by sensory input from an unpredicted perturbation, such as the surface moving or by a bump to the body. These are examples of sensory input initiating motor output, and therefore they have been termed "feedback" postural activity.<sup>30,31</sup> In contrast, maintenance of postural stability can be disrupted in a predictable manner when we perturb ourselves, such as when we initiate a movement. Postural adjustments related to voluntary movement in some instances in both children and adults been shown to be initiated prior to the start of the movement.<sup>24,29,32-34</sup> This anticipatory postural muscle activity helps to achieve smooth execution of the desired movement. Because there is no initial sensory input triggering this anticipatory postural muscle activity, it has been termed "feedforward" postural control.<sup>30,31</sup> Haas et al<sup>31</sup> found, in children who were developing in a typical manner and who ranged in age from 7 months to 14 years 8 months, that feedback postural control develops earlier than feedforward postural control. They reported, however,

that the development of feedback control is not complete when feedforward control appears.<sup>31</sup> This finding suggests that the control system for feedforward versus feedback postural stability may be different. Therefore, if an individual only shows problems with feedforward postural stability, the therapist may not want to spend time in therapy applying unpredictable perturbations to provoke balancing responses.

We believe that for children, therapists need to be aware of the developmental sequence of postural control, especially for discriminative testing. In typically developing children, the growth of postural stability proceeds in a cephalocaudal fashion, with the infant achieving control of the head, then the trunk, and finally postural stability in standing.<sup>2,22-24</sup> Extensive studies on the development of standing balance from a sensory and motor developmental perspective have been done.<sup>29,35-41</sup> This research has shown that, from a motor systems perspective, the sequence of activation of muscles reacting to a specific type of perturbation—pulling the floor backward or forward under the feet—appears to be generally in place as early as 18 months of age.<sup>28,35,37</sup> The timing and amplitude, however, of these coordination patterns or motor response strategies are not mature. The coordination of the postural response goes through a transitional stage at 4 to 6 years of age, reaching adultlike maturity by 7 to 10 years of age.<sup>28,35,37</sup> This transition of postural responses at 4 to 6 years of age results in less-coordinated motor patterns in terms of timing and selection of strategy. This finding has been hypothesized to be related to the growth spurt that occurs in most children during these years, resulting in alteration of the child's biomechanical characteristics.<sup>37</sup>

The ability of the sensory systems to detect imbalance during standing also follows a developmental sequence.<sup>28,35,37</sup> Infants and young children (aged 4 months to 2 years) are dependent on the visual system to maintain balance.<sup>34,42-44</sup> When children of this age are placed in a room with movable walls, they consistently fall in the direction that the walls are moved.<sup>44</sup> At 3 to 6 years of age, children begin to use somatosensory information appropriately.<sup>35-38</sup> Finally, at 7 to 10 years of age, children are able to resolve a sensory conflict (mismatched information coming from somatosensory and visual receptors) and appropriately utilize the vestibular system as a reference.<sup>35-38</sup> Interestingly, at 7 to 10 years of age, the gait pattern also reaches full maturity.<sup>45</sup> Because children who are developing in a typical fashion change from a dominant reliance on visual input to an ability to rely on somatosensory input and utilize the vestibular system as a reference in conditions of sensory conflict, the therapist must take into consideration the developmental level of the child when making judgments about sensory system deficits of postural stability.

For all tests and measurements, information on developmental sequence, if available, will be noted.

Individual discussions of the currently available tests for evaluating postural stability at the impairment and functional limitation dimensions in children follows. For quick reference, Tables 1 and 2 summarize a few details about all tests described.

## Impairment Dimension Measurements of Postural Stability

### *Methods of Measuring the Sensory Systems*

The tests described in this section are designed to assess the three sensory systems (visual, somatosensory, vestibular) that contribute to postural stability. The rationale underlying the use of these tests is that accurate assessment of sensory systems can identify deficits in sensory processing that affect the ability to execute an appropriate postural response.

Assessment of sensory components of balance is rooted in diagnostic tests for evaluating the vestibular system. The vestibular system has two components related to maintenance of posture—one to maintain visual clarity (the vestibulo-ocular component) and the other to facilitate postural reactions in the neck, trunk, and limbs (the vestibulospinal component).<sup>46–48</sup> Interaction of the vestibular system with other sensory systems is measured in differing degrees in the various tests. Tests such as past pointing, the Romberg test, and tandem walking have been used by physicians and by physical therapists and occupational therapists to obtain gross estimates of the function of the vestibular system.<sup>49</sup> Although these tests may provide information on postural stability, uncontrolled effects of cerebellar, visual, or musculoskeletal dysfunction can affect an individual's performance on these tests.<sup>49,50</sup> These tests, therefore, are not specific or sensitive enough to assess vestibular function in isolation.<sup>49,50</sup>

Similar problems are found with other commonly used clinical assessments of postural stability, such as tiltboard tip tests. One standardized version of a tiltboard test requires the therapist to tip the tiltboard while the child stands with feet together and hands on hips.<sup>51</sup> The therapist observes how far the tiltboard can be tipped before the child loses balance or steps off. The therapist measures the tilt against a backdrop marked with angles. This test has been done with both eyes open and eyes closed. Performance on this test reflects the child's ability to balance in varying sensory conditions. The eyes-open test should reflect balancing with use of all three senses, whereas the eyes-closed test requires interaction from the somatosensory and vestibular senses.<sup>4</sup> This test was originally developed because children with

postural instability have difficulty balancing in this situation and sometimes demonstrate an uncontrolled fall.<sup>4–6,52</sup> Although this tiltboard test is of some clinical use in determining a child's responses to external perturbations of postural stability ("feedback" tests), in our opinion, it is not a test that systematically discriminates problems with individual sensory inputs. The tiltboard tip tests have good interrater reliability (Spearman  $r = .98$ ), but poor test-retest reliability in both children with and without balance dysfunction (intraclass correlation coefficients [ICC] = .52–.82 and .49–.54, respectively)<sup>52</sup> (Spearman  $r = .45$ ).<sup>51</sup> Children's performance on this balance task appears to fluctuate from one session to another, and in the eyes-closed test, a learning effect appears to be present in repeated trials of the task.<sup>51,52</sup> These findings suggest that this test should not be used for evaluative purposes. Because results appear to differentiate between children with and without disabilities,<sup>4,5,51,52</sup> however, this test may be an appropriate screening tool for determination of the need for further evaluation of postural stability.

A clinical test of vestibular function, particularly the vestibulo-ocular component, that has been widely used by pediatric therapists is the Postrotary Nystagmus Test (PRN).<sup>53</sup> In this test, the child sits on a rotating platform with the neck flexed forward to 30 degrees to stimulate the horizontal semicircular canals. The child is spun by the therapist for 20 seconds, after which duration of nystagmus is observed. According to Ayres,<sup>53</sup> either hypoactive or hyperactive nystagmus is indicative of vestibular dysfunction. The interrater reliability of measurements obtained with the PRN is good (Pearson  $r = .83$ ); however, the test-retest reliability is poor (Pearson  $r = .49$ ).<sup>53–55</sup> The validity of the PRN has been questioned due to procedural problems (testing is done in a lighted room with eyes open, which provides visual as well as vestibular stimulation), as well as concerns regarding the reliability of the normative data obtained for postrotary nystagmus.<sup>56,57</sup>

Vestibulo-ocular reflex (VOR) testing permits measurement of reflexive eye movements driven by the vestibular system. The individual being tested is rotated while seated in a chair in a dark room. Surface electromyographic (EMG) activity is recorded from eye muscles during and after the rotation. Although this method of testing provides measurements of the function of the horizontal semicircular canals, it does not measure the status of the vertical canals or the otoliths, or on a larger scale the vestibulospinal component.<sup>50</sup> Vestibulo-ocular reflex testing is most effective at measuring peripheral vestibular function.<sup>49</sup> Because vestibular processing deficits in children appear to be most commonly due to central nervous system dysfunction,<sup>4,50</sup> however, this test is less effective in identifying vestibular deficits in a

**Table 1.** Impairment Tests of Postural Stability in Children<sup>a</sup>

Test Type	Test Name	Age Range (y)	Outcome Variable	Reliability		Test-Retest	Construct Validity	Normal Data	Recommended Use
				Intrater	Interrater				
Sensory system	Tiltboard <sup>51,52</sup>	4-9	Tilt (°)	$r_t = .98$		$r_t = .45$ ICC = .49-.82	Sig diff DD	5-9 y (N=226)	Discriminative
	PRN <sup>53-55</sup>	3-10	Time nystagmus	$r_p = .83$		$r_p = .49$			Discriminative (peripheral vestibular)
	Posturography <sup>6-11,28,35,52,66</sup>	1.5-10	Sway by sensory condition	Computer scored			Sig diff LD, CP DS, EP PM, HI		Discriminative
Motor system	P-CTSIB <sup>14,38,39,59-62</sup>	4-9	Time/sway and sensory system scores	$r_t = .69-.90$		$r_t = .45-.78$ ICC = .55-.88	Sig diff LD, CP $r_s = .63-.68$	4-9 y (N=120)	Discriminative
	Observe during P-CTSIB <sup>51,59,62,67</sup>	4-12	Strategy use (ankle, hip, step, crouch)	Kappa = .39-.68		Kappa = -.10-.36			None
	COMPS <sup>68,70</sup>	5-9	Movement quality during six tasks	ICC = .76-.88		ICC = .79-.92	Sig diff DCD	5-9 y (N=56)	Discriminative Perhaps evaluative
	Side reach <sup>71,72</sup>	5-12	Balance strategy quality (head, trunk, arm, and leg position)	$r_p = .98$			Sig diff LD		Discriminative
Biomechanical system	Posturography <sup>7,8,28,32-35</sup>	1.5-10	EMG timing, amplitude, sequence	Computer scored			Sig diff CP, DS		Discriminative
	MMT <sup>82-85</sup>	3-adult	Ordinal strength score	ICC = .90		ICC = .80-.96 Kappa = .65-.93	Sig diff DMD		Discriminative
	HHD <sup>62,79,86-92</sup>	3-adult	Muscle force	ICC = .84-.99		$r_p = .74-.99$ ICC = .75-.99	Sig diff CP, DS	5-11 y (N=98)	Discriminative
	Standard goniometry <sup>94-99</sup>	Any age	ROM (°)	ICC = .25-1.00		ICC = .33-.97 SEM = 2.3-6.7	Sig diff CP, DS		Discriminative
	Video goniometry <sup>79,100</sup>	Any age	ROM (°)	ICC = .84-.99					Discriminative

<sup>a</sup> Abbreviations used:  $r_p$  = Pearson Product-Moment correlation coefficient,  $r_t$  = Spearman rho correlation coefficient, ICC = intraclass correlation coefficient, SEM = standard error of measurement, sig diff = statistically significant difference, DD = developmental delay, LD = learning disability, CP = cerebral palsy, DS = Down syndrome, EP = epilepsy, PM = premature, HI = hearing impairment, DCD = developmental coordination disorder, DMD = developmental motor disorder, PRN = Postrotary Nystagmus Test, P-CTSIB = Pediatric Clinical Test of Sensory Interaction for Balance, COMPS = Clinical Observation of Motor and Postural Skills Test, MMT = manual muscle test, HHD = hand-held dynamometry, ROM = range of motion.

**Table 2.** Functional Limitation Tests of Postural Stability in Children<sup>a</sup>

Test Type	Test Name	Age Range	Outcome Variable	Reliability		Validity		Normal Data	Recommended Use
				Intrater	Interrater	Construct <sup>b</sup>	Concurrent <sup>c</sup>		
Developmental	AIMS <sup>102</sup>	0-18 mo	Movement quality	$r_p = .96-.98$	$r_p = .99$	$r_p = .95-.99$	$r_p = .84-.99$ (BSID, PD, MS)	1-18 mo (N=2,400)	Discriminative Predictive Evaluative
	MAI <sup>103,105,106</sup>	0-12 mo	Risk score; movement quality	$r_p = .51-.78$		$r_p = .16-.87$ Kappa = .75-.97	67%-74% correct for predicting CP; 35%-63% correct for TD		Discriminative Predictive Evaluative
	BSID II <sup>104</sup>	0-42 mo	No. of motor skills	$r_p = .75-.96$	Fisher $z =$ .84-.88	$r_p = .78-.87$	No sig diff BSID	1-42 mo (N=1,700)	Discriminative Evaluative
	PDMS <sup>81</sup>	0-83 mo	Motor skill performance	$r_p = .94-.99$		$r_p = .80-.99$	Sig diff DP	1-83 mo (N=617)	Discriminative Evaluative
Activities of daily living (ADL)	BOTMP <sup>80</sup>	4.5-14.5 y	Motor skill performance	$r_p = .90-.98$		$r_p = .56-.81$	$r_p = .57-.86$ (age) Sig diff MR, LD	4.5-14.5 y (N=765)	Discriminative Evaluative
	GMFM <sup>76</sup>	2-5 y	Quality of motor skills	ICC = .87-.99	ICC = .92-.99	ICC = .85-.98	Responsive to change		Discriminative Evaluative
	PEDI <sup>107</sup> (not including Social Function section)	0.5-7.5 y	No. of ADL skills, caregiver assistance, modifications	ICC = .79-1.00		ICC = .74-.96	(rehabilitation team to family)	0.5-7 y (N=412)	Discriminative Evaluative
Single-item tests	CHAQ <sup>108,109</sup>	1-19 y	Independence of ADL			$r_s = .80$ ICC = .87-.96	Kendall tau = .77 (SFC)		Evaluative
	JASI <sup>110</sup>	8-18 y	Independence of ADL						None yet, needs more research
	FRT <sup>61,111-113</sup>	5-15 y	Distance reached	ICC = .98 Kendall tau = .85	ICC = .83-.97	ICC = .64-.75 (TD) ICC = -.31-.34 (DD)		5-15 y (N=116)	Discriminative
	TUG <sup>82,75</sup>	3 y-adult	Time to get up, walk 3 m, and sit down	ICC = .99					Discriminative
	FST <sup>114-116</sup>	12-30 y	Time doing functional mobility tasks in standing position	ICC = .60-1.00					Discriminative

<sup>a</sup> Abbreviations used:  $r_p$  = Pearson Product-Moment correlation coefficient,  $r_s$  = Spearman rho correlation coefficient, ICC = intraclass correlation coefficient, TD = typically developing, DD = developmental delay, MR = mental retardation, LD = learning disability, AIMS = Alberta Infant Motor Scale, MAI = Movement Assessment of Infants, BSID II = Bayley Scales of Infant Development-2nd edition, PDMS = Peabody Developmental Motor Scales, BOTMP = Bruininks-Oseretsky Test of Motor Impairment, GMFM = Gross Motor Function Measure, PEDI = Pediatric Evaluation of Disability Index, CHAQ = Childhood Health Assessment Questionnaire, JASI = Juvenile Arthritis Status Index, FRT = Functional Reach Test, TUG = timed "up and go" test, FST = Functional Standing Test, BSID = Bayley Scales of Infant Development-1st edition, MSCA = McCarthy Scales of Children's Abilities, WHGM = West Haverstraw Gross Motor Test, SCSIT = Southern California Integration Test, WF = Wee Fim, BDIST = Battelle Developmental Inventory Screening Test, SFC = Steinbrocker Functional Classification.

<sup>b</sup> Sig diff = statistically significant difference between typically developing subjects and indicated population with disability.

<sup>c</sup> Correlation coefficients reported compare the test with other tests named.

pediatric population. Additionally, the equipment required for VOR testing makes it relatively impractical for clinical use.

The measurement of postural sway in the presence of sensory conflicts provides a means for evaluating deficits in central sensory organization.<sup>35,38</sup> *Sensory organization* is the ability of an individual to select from among the redundant sensory inputs to identify the sensory system that is providing the most accurate input for maintaining postural stability. Forssberg and Nashner<sup>35</sup> described the technique of sensory organization posturography testing, in which postural sway is measured in response to varying visual and somatosensory conditions. This technique permits systematic study of visual, somatosensory, and vestibular inputs for postural orientation. The individual stands on a computer-controlled movable force platform facing the center of a three-sided movable visual enclosure. The support surface and visual surroundings can be rotated in proportion to body sway, thus providing inaccurate visual and somatosensory inputs regarding the orientation of the body's COM. Body sway is measured while the individual stands for 30 seconds under six sensory conditions: (1) eyes open, normal surface (all three sensory systems providing accurate information about body position), (2) eyes closed, normal surface (only somatosensory and vestibular information available), (3) visual conflict, normal surface (sensory conflict due to inaccurate visual information but accurate somatosensory and vestibular information), (4) eyes open, somatosensory conflict (sensory conflict due to inaccurate somatosensation), (5) eyes closed, somatosensory conflict (no vision; inaccurate somatosensation, so vestibular information must be used), and (6) visual conflict, somatosensory conflict (only vestibular system providing accurate information).<sup>28,35</sup>

This method has been used to document developmental changes in sensory organization strategies in children<sup>28,35</sup> as well as deficits in sensory organization strategies in children who have motor deficits as a result of learning disabilities,<sup>6,50</sup> cerebral palsy,<sup>7</sup> Down syndrome,<sup>8</sup> epilepsy,<sup>9</sup> prematurity,<sup>10</sup> and hearing impairments.<sup>4,11</sup> Different diagnoses appear to present either no sensory deficit or different patterns of sensory deficits.<sup>4-10,50</sup> Platform posturography measurement of sensory organization is being used with increasing frequency in clinics, despite the high cost of the apparatus.

Several less expensive platform force-plate measurement systems have been used to document sensory deficits in children with exposure to high lead levels early in life<sup>12</sup> and in children with autism.<sup>13</sup> Interrater reliability has not been reported. Studies of test-retest reliability, if completed, have not been published in peer-reviewed

journals. Evidence for construct validity has been obtained by comparing the performance of typically developing children and with that of children who have deficits in postural stability.<sup>12,13</sup>

Another test of sensory function related to balance, the Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB), was developed to provide an inexpensive, clinical alternative to platform posturography.<sup>59,60</sup> The P-CTSIB, which is based on a suggestion from the field of physical therapy,<sup>58</sup> uses the same six sensory conditions that are used in platform posturography. Visual conflict is provided by use of a hatlike apparatus made of a lightweight dome. The dome allows some diffuse light to come through, but impedes the peripheral vision. As the child sways, the dome moves in synchrony with the head to simulate the moving visual surround of the platform posturography tests.<sup>59</sup> Somatosensory conflict is provided by having the child stand on a layer of medium-density closed-cell foam, which dampens somatosensory input during somatosensory conflict conditions. Both the amount of time the child can stand in a feet-together position and an observational measurement of anteroposterior sway are recorded.

These raw measurements are then combined for each of the six conditions and transformed into an ordinal scale spanning inability to balance in the condition to balance for the maximum of 30 seconds with less than 5 degrees of sway. These ordinal scores are then summed across sensory conditions to yield sensory system scores that are thought to provide the tester with information about whether the child can process and use each of the three sensory systems (visual, somatosensory, and vestibular). Interrater reliability<sup>59</sup> and test-retest reliability<sup>60,61</sup> have been established for this tool for both children with and without disability. Although interrater reliability for sway measurements is moderate to good (Spearman  $r = .69-.90$ ),<sup>59</sup> test-retest reliability is lower (Spearman  $r = .51-.88$ ).<sup>60,61</sup> Pilot norms have been established for typically developing children.<sup>38,39</sup> Overall, it appears that this is an easy test for typically developing children aged 4 to 9 years to perform. The children are able to stand for 30 seconds with less than 5 degrees of sway in all conditions except the last two conditions, where the time may drop by a few seconds and the sway increases by several degrees, especially in the younger children. The P-CTSIB has been used to identify sensory organization differences between children who are typically developing<sup>38,39</sup> and subsets of children with learning disabilities<sup>14</sup> and cerebral palsy,<sup>56</sup> which demonstrates some construct validity for the test. Scores on the P-CTSIB also correlate with functional activities related to postural stability (Spearman  $r = .63-.68$ ); therefore, performance on the test reflects functional ability to some extent.<sup>62</sup> Due to the level of interrater reliability and the begin-



ning normative and validity information, this test could be useful for discriminative purposes. Due to what we consider to be the moderate test-retest reliability, however, we do not believe that this test is appropriate for evaluative purposes.

### *Methods of Measuring the Motor System*

Evaluation of motor coordination is the core of the pediatric physical therapists' and occupational therapists' expertise and practice.<sup>63</sup> Observational analysis of motor coordination during balancing is one method of evaluating this system. Due to the complexity of the musculoskeletal system and the variable environmental conditions in which we move, the motor coordination component of balancing has an infinite number of options for muscle activation for maintenance of postural stability. This multitude of options could make observational analyses of motor coordination very difficult due to the variability of potential responses. The general systems theory of motor control<sup>12,18,23</sup> postulates that there are predetermined motor strategies that help to reduce the complexity of choice of a coordinated motor response.<sup>64-66</sup>

Experiments that moved the floor surface forward or backward showed three basic coordination patterns during standing in adults and children: (1) an ankle strategy (primary sway centered on the ankle joint), (2) a hip strategy (primary sway centered on the hip joint), and (3) a stepping strategy (increasing the BOS).<sup>66</sup> Choice of these strategies is related, in part, to the strength of the perturbation, with a strong perturbation causing the stepping response, a weaker perturbation causing the hip response, and a very weak perturbation eliciting an ankle response. Other influences on choice of strategy include the surface on which the individual is balancing and availability of sensory cues.<sup>66</sup>

Therapists have observationally evaluated motor coordination during maintenance of postural stability by placing the child on a movable surface, tilting or moving the surface under the child, and subjectively grading the motor response observed due to the perturbation. This information is often reported as "clinical observations" and is intended to document whether the child has the appropriate balancing motor strategies (ie, head and trunk righting, arm and leg counterbalancing, and protective extension). These three motor strategies are similar to the ankle, hip, and stepping strategies, respectively, documented through the research on balancing in standing noted earlier. This type of assessment has not been examined for reliability. In an effort to improve this type of assessment, a few tests have been developed to assess in a standardized manner the motor coordination related to postural stability.

Generalizing the use of the three defined standing strategies (ankle, hip, stepping)<sup>66</sup> to balance on one leg<sup>51</sup> and to the systematically altered sensory input conditions of the P-CTSIB,<sup>59</sup> researchers coded in real time the use of these strategies. Interrater reliability during one-leg standing was poor to moderate (Kappa = -.10-.36).<sup>51</sup> During the P-CTSIB, the interrater reliability was questionable in children who were typically developing (percentage of agreement = 92%-100%, but noncomputable Kappas), in part due to limited variability of motor coordination patterns observed.<sup>59</sup> The children appeared to use primarily an ankle strategy. Further research on children with cerebral palsy observationally scored balancing motor strategies as an ankle, hip, or crouch strategy (defined as flexion of the hips and knees in an attempt to lower the COM) during the P-CTSIB, except both P-CTSIB examiners scored independently.<sup>62</sup> (With the P-CTSIB, one examiner spots the child and the other examiner sits back several feet to judge sway of the child against the grid backdrop.) These scores were compared, and the reliability was moderate (weighted Kappa = .68).<sup>62</sup> Videotapes were made of the children during this study. These videotapes were later coded by viewing the tape once, and comparisons were made among three raters who independently scored the videotapes and with each rater scoring the videotapes on two different occasions.<sup>67</sup> The interrater and intrarater reliability was moderate among the three raters using the videotapes (weighted Kappa = .51-.58 and .54-.69, respectively). These researchers noted that repeated viewing of the videotapes may improve the reliability, but a more detailed analysis of the strategy through use of EMG may be necessary.<sup>67</sup> Further modification and testing of this system of coding motor coordination responses are needed, in our view, before this can be a viable measurement system.

The Clinical Observations of Motor and Postural Skills (COMPS)<sup>68</sup> was based on Ayres' original nonstandardized clinical observations used in conjunction with the Southern California Sensory Integration Tests.<sup>69</sup> Item administration and scoring have been standardized, yielding good interrater and test-retest reliability (ICC[3,1] = .76-.88 and .79-.92, respectively).<sup>70</sup> Construct validity has been demonstrated by showing statistically significant differences between scores of children with developmental coordination disorders and children who were typically developing.<sup>70</sup> The test is composed of six items: (1) slow motion, (2) finger-nose touching, (3) rapid forearm rotation, (4) prone extension, (5) quadruped testing of the asymmetrical tonic neck reflex, and (6) supine flexion posture. Children are rated on their motor coordination during the activities. This test provides a summary of feedforward motor coordination during these activities, including maintenance of postural stability during dynamic movements

(items 1, 2, and 3) as well as static movements (items 4, 5, and 6). The COMPS would be recommended for discriminative testing, and perhaps as an evaluative measure at the impairment dimension. The test could also be used diagnostically if the tester accepts the theoretical constructs behind each of the items and designs treatment accordingly.

Fisher and Bundy<sup>71,72</sup> developed a flat-board and tilt-board reach test for measuring motor coordination during balancing. This test is different from the tiltboard tip test discussed earlier because the type of motor coordination used to maintain balance is the measured variable. The child is videotaped standing on either a flat board or a tiltboard with feet slightly apart and reaching as far laterally as he or she can for a toy held by the examiner. A standardized method for scoring head and trunk position and arm and leg counterbalancing was developed and found to have good interrater reliability (Pearson  $r = .98$ ) when videotaped images were scored.<sup>71</sup> Test-retest reliability has not been examined. Construct validity has been established because the test discriminates between children with learning disabilities and children who are developing in a typical fashion.<sup>72</sup> This test is unique because it provides a measurement of a feedforward postural response during the relatively functional task of reaching laterally. With the results, identification of motor coordination problems may be localized to head, trunk, or arms and legs so that a general strategy selection problem can be identified. This test, therefore, could be useful discriminatively, but due to the lack of test-retest reliability, it cannot be used to evaluate progress.

A limitation of all of the tests discussed is that they cannot be used to determine actual selection, timing, sequencing, and amplitude of muscle activity during the motor response. Tests have been developed that record and process, via computer technology, surface EMG activity and two- or three-dimensional kinematic for the motor coordination of postural responses. Some developmental information has been gathered for children during platform perturbation testing,<sup>28,35</sup> as well as for recording after an auditorily cued arm-pull perturbation during the gait cycle.<sup>32,33</sup> Information on the coordination patterns of small groups of children with cerebral palsy<sup>7</sup> and Down syndrome<sup>8</sup> is available. These studies provide some specific information regarding the differences between "normal" and "aberrant" patterns. Although there may be similarities among children with the same diagnosis, there are wide ranges of responses. Each child's condition, therefore, needs to be evaluated individually. Additionally, the aberrant patterns adopted by children with disabilities may be the most efficient and appropriate patterns for their own individual systems. For example, some preliminary research suggests

that when children who are developing typically adopt a crouched posture similar to that of children with spastic diplegia, they exhibit a similar EMG response to a backward movement of a force platform.<sup>73</sup> This finding suggests that the coordination of the motor pattern response may not always be the limiting factor, but rather biomechanical differences of the starting position may determine the response.

#### *Methods of Measuring the Biomechanical System*

Two main biomechanical factors have been shown to be related to postural stability in children: force output and range of motion (ROM). Force output has been shown to be related to functional measures of movement that require postural stability, such as running speed,<sup>74</sup> the timed "up and go" mobility test,<sup>75</sup> and the Gross Motor Function Measure,<sup>76</sup> and to measures of ambulation efficiency in children with cerebral palsy.<sup>74,77,78</sup> Force output has also been shown to be related to performance on the gross motor subtest of the Peabody Developmental Motor Scales (PDMS-GM) in children with Down syndrome.<sup>79</sup> Similarly, ROM is related to running speed<sup>80</sup> and the timed "up and go" mobility test<sup>75</sup> in children with cerebral palsy<sup>74</sup> and to PDMS-GM<sup>81</sup> scores in children with Down syndrome.<sup>79</sup>

Although there are relationships, as noted above, of force output and ROM to performance of children's motor activities, simply improving a child's strength or ROM does not guarantee improved postural stability or function. Most daily activities do not demand that the child use a maximal force output or move through a full ROM. The amount of force output or ROM that is required to perform daily activities successfully remains unknown. Because children with motor impairment frequently have ROM limitations and a decreased ability to generate force, assessment and remediation of these biomechanical factors, in our view, should be considered during treatment planning for remediation of all motor activities involving maintenance of postural stability.

Force output has often been evaluated using manual muscle testing (MMT).<sup>82,83</sup> Advantages of MMT include the fact that it requires no special equipment and can be performed in any location. One of the problems with using MMT in children is the variability in different raters' ability to judge the amount of resistance required for a rating of Normal, as this ability varies with the individual's age and with the selected muscle groups.<sup>82</sup> Good intrarater reliability (weighted Kappa = .65-.93 and ICC = .80-.96)<sup>84,85</sup> and interrater reliability (ICC = .90),<sup>85</sup> however, have been shown for trained examiners for 18 upper- and lower-extremity muscle groups in children with Duchenne or Becker muscular dystrophy.

Hand-held dynamometry is another clinically feasible method of quantifying force output that uses a strain gauge to record peak torque and is relatively inexpensive. Bohannon<sup>86</sup> has documented standard testing positions for dynamometry, and other therapists have advocated modifications of these positions to improve the specificity of testing (Susan K Effgen, personal communication, 1995). For trained examiners, interrater reliability has been shown to be good for lower-extremity muscles in children with cerebral palsy (ICC[3,1]=.94-.99),<sup>62</sup> children with Down syndrome (ICC[2,1]=.92-.98),<sup>79</sup> and children who were developing typically (ICC[3,1]=.84-1.00).<sup>87</sup> Intrarater reliability was good in children with Duchenne muscular dystrophy (Pearson  $r$ =.83-.99).<sup>87</sup> Test-retest reliability was also found to be good in children with meningomyelocele (ICC=.75-.99),<sup>88</sup> children with moderate mental retardation (ICC=.83-.86),<sup>89</sup> children with Duchenne muscular dystrophy (Pearson  $r$ =.83-.99),<sup>87</sup> and children who were developing typically (ICC=.79-.93).<sup>90</sup> Dynamometers are advantageous because they are small and portable equipment. One disadvantage is that broad normative data are not available for the pediatric population. Information on small samples has been documented, however, and could be used as a general guide for decision making.<sup>91,92</sup>

Both MMT and dynamometry could aid with the identification of impairments in children. Each test could also be used for evaluative purposes if interrater and test-retest reliability were established by the examiners prior to use. To minimize the chance of examiner error, we suggest that the same rater perform all the measurements.<sup>84,87</sup> A disadvantage of both MMT and dynamometry is that neither test provides information about force generation throughout the ROM during concentric and eccentric contractions or during functional activities.

Isokinetic testing devices have the advantage of generating information through an arc of motion. The machine provides resistance to hold the speed of the motion constant. Disadvantages include the cost of the equipment, lack of portability, difficulty in adapting the devices to small children, and lack of research on children. Another disadvantage is that test results are limited to specific speed selections rather than measuring force output in a functional context.

All three of the force output testing methods discussed involve eliciting a maximal effort. The ability to obtain a maximal effort can be influenced by the child's age or cognitive level. Good test-retest reliability (ICC=.79-.93) of hand-held dynamometry measurements of shoulder and knee flexion and extension has been shown in a small sample of girls as young as 3 years of age.<sup>90</sup> Children with cognitive deficits may have difficulty with

the procedures, regardless of their age. Horvat and colleagues,<sup>89</sup> however, have recently demonstrated good test-retest reliability, both within and between sessions (ICC=.83-.86), using hand-held dynamometry for elbow flexion and extension with individuals aged 14 to 24 years who had moderate mental retardation. Examiners should be aware that cooperation and performance can vary with individual children. In young children, force output is similar for boys and girls. As children enter puberty, however, gender differences develop. Clinical judgments for adolescents, therefore, must be made in comparison with same-gender peers.<sup>91</sup>

Children with neurological impairment present additional challenges. Frequently, due to the decreased ROM that can accompany neurologic impairment, the testing positions place the children at the end of their joint ROM. This puts the child at a mechanical disadvantage because the muscle's position is at the end of the length-tension curve. Additionally, children with neurological impairment may have impaired motor control or can only move in synergistic patterns. If a child is unable to push against the testing apparatus, it is difficult to ascertain whether all or a portion of the deficit is due to weakness or to an inability to voluntarily move the extremity in the desired direction on command.

Maintaining postural stability often requires controlled, sustained adjustments rather than maximal bursts of activity. These sustained low-level contractions may not be difficult for children who are developing typically, but they may be impossible in children with neurological dysfunction because of their very low force output ability, poor endurance, and poor biomechanical alignment.<sup>93</sup> Limited data exist about which muscles are important and how much force production is necessary for control of posture. Preliminary data on a small sample of children with cerebral palsy suggest that the ability to generate hip extension, hip abduction, and ankle plantar-flexion force is most important for maintaining postural stability in a standing position.<sup>62</sup> Much research is needed in this area.

Weakness may also force children to use biomechanical alignment for stability. The children may adopt a posture in which they can use gravity and alignment rather than muscle contractions to maintain upright stance. For example, a child may stand with an increased lumbar lordosis to shift the center of gravity farther behind the hip joint, thereby allowing the iliofemoral ligament to provide passive hip extension. Similarly, the child may hyperextend the knees to move the center of gravity farther in front of the knee and provide passive knee extension. By standing in this "knee-locked" position, however, the child assumes a less dynamic posture and is

less ready to move to maintain postural stability. These positions may lead to contractures.

Range of motion has been evaluated by standard goniometric techniques.<sup>94</sup> In children with disabilities, interrater and test-retest reliability of goniometric measurements has been problematic because both types of reliability can be influenced by numerous factors such as illness, temperament, medication, and speed of movement.<sup>95-99</sup> The presence of increased reflex activity also may cause inconsistent because muscle length can change based on the duration, intensity, and speed of force exerted to passively move the limb and can provide a more variable end feel than bone or typical soft tissue.<sup>98</sup> Two studies on children with cerebral palsy<sup>95,98</sup> showed the reliability agreement among raters' measurements of ROM may be 10 to 15 degrees apart. In a more recent study,<sup>99</sup> intrarater reliability for standard goniometry in ankle joints of children with juvenile rheumatoid arthritis, children with cerebral palsy, and children who were developing typically has been shown to be moderate to good (standard error of measurement [SEM]= $\pm 2.3^{\circ}$ - $6.7^{\circ}$ ). The low SEM of 2.3 degrees was for children who were typically developing when the same rater used an average of two measurements. The high SEM of 6.7 degrees was for children with cerebral palsy when different raters measured over time. In children with Duchenne muscular dystrophy, intrarater reliability was higher (ICC=.81-.94) than interrater reliability (ICC=.25-.91).<sup>97</sup> The basic recommendation if using goniometry for evaluative purposes in children is to control the external conditions carefully and always have the same examiner remeasure.<sup>96,99</sup>

Use of videography has been shown to improve goniometric interrater reliability (ICC[2,1]=.84-.99) in children with Down syndrome.<sup>79</sup> Bony landmarks are identified with markers. The child is positioned at a 90-degree angle to the camera, and the ROM procedures are recorded on videotape. The joint angle measurements are then taken from the videotape by freezing a frame and using a goniometer on the screen. Computer methods for measuring kinematic variables can also be used to make the measurements.<sup>100</sup> Although reproducibility and accuracy are generally good (ICC=.99) using computer-scored videography,<sup>100</sup> care must be taken to ensure that the video picture is a valid representation of the child's excursion.<sup>79</sup> Factors such as camera angle and selection of which video frame to analyze could distort the information. This type of ROM measurement allows the therapist to record ROMs that are voluntarily used in functional activities rather than the actual full ROM. Research on these ROMs could provide important information about critical values necessary for maintenance of postural stability.

In addition to providing sufficient range of movement to make postural adjustments, theoretically adequate ROM is necessary to optimize the pull of gravity and to maximize the child's BOS. For example, the common stance of children with spastic diplegia with ankles plantar flexed and hip medially (internally) rotated and adducted considerably narrows the child's BOS. This narrowing of the BOS, in turn, could accentuate the impact of external perturbations, as it becomes more difficult to maintain the center of gravity inside a narrow BOS. Decreased ROM also changes the line of pull of gravity. In typical adult posture, the line of gravity falls slightly behind the hip joint and in front of the knee and ankle joints.<sup>101</sup> This alignment allows the body to use ligamentous and bony alignment to provide some stability rather than using excessive muscle activity. Typically, the plantar flexors are the only muscles that are active when standing still, unless the sway becomes excessive.<sup>101</sup> Introducing even a small knee flexion contracture can disrupt this alignment, shift the line of gravity, and therefore theoretically create a situation in which the child needs to actively contract the quadriceps femoris muscles to maintain a standing position. Research is needed in this area to better define critical values of ROM and the postural alignment necessary for improved postural stability.

### **Functional Limitation Dimension Measurements Reflecting Postural Stability**

Adequate postural stability is necessary to perform basic gross motor skills, and these skills can, in one sense, be defined as the "functional" activity of children. Therefore, assessments that analyze gross motor skill acquisition can provide information regarding a child's postural stability at the level of functional limitations.

There are several developmental assessment instruments designed for infants and young children that are based on the typical sequence of motor skill acquisition. Examples are the Alberta Infant Motor Scale,<sup>102</sup> the Movement Assessment of Infants,<sup>103</sup> the Bayley Scales of Infant Development (2nd edition),<sup>104</sup> and the Peabody Developmental Motor Scales (PDMS).<sup>81</sup> These tests have moderate to good reliability and validity.<sup>21,102-106</sup> (Actual coefficients are detailed in Tab. 2.) Generally, these tests have specific sections related to postural stability. For example, the PDMS is designed for children from birth to 83 months of age and includes a balance subtest as part of the gross motor scale.<sup>81</sup> The balance subtest includes items such as one-foot balance and walking on a balance beam. For older children (aged 4.5-14.5 years), the gross motor section of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP)<sup>80</sup> provides a reliable balance subtest, with items similar to those of the PDMS, as well as subtests on running speed and agility, bilateral coordination, and strength. Moder-

ate to good reliability and validity have been documented.<sup>80</sup> (Refer to Tab. 2 for the actual coefficients.) The BOTMP was designed for children with mild motor impairment and is very difficult for children with more severe impairment to complete. For children with cerebral palsy, the Gross Motor Function Measure (GMFM)<sup>76</sup> has good interrater and test-retest reliability (Tab. 2).<sup>21,76</sup> Items tested fall under five domains: (1) lying and rolling, (2) crawling and kneeling, (3) sitting, (4) standing, and (5) walking, running, and jumping. All of these domains require postural stability. The GMFM has also been shown to be responsive for evaluation of clinically meaningful change.<sup>21</sup>

Tests such as the Pediatric Evaluation of Disability Inventory (PEDI)<sup>107</sup> and two tests designed for children with juvenile rheumatoid arthritis, the Childhood Health Assessment Questionnaire (CHAQ)<sup>108,109</sup> and the Juvenile Arthritis Status Index (JASI),<sup>110</sup> are examples of tools used to measure children's ability to perform activities of daily living rather than developmental skills. The PEDI uses an interview or observational format and consists of three sections: self-care, mobility, and social function. Studies have shown the PEDI to have good reliability and validity.<sup>107</sup> (Refer to Tab. 2 for actual coefficients.) The CHAQ and JASI are questionnaires that determine the types of activities that children are capable of doing independently in their normal environments. Performance of all mobility and self-care tasks requires adequate postural stability.

These developmental and functionally based tests measure many aspects of movement. By focusing on specific items within the scales, we believe that these tests can be used as discriminative tests to document general problems with postural stability. They are also useful as evaluative measures to document functional movement changes related to treatment of postural stability. Care, however, should be taken regarding the population being evaluated due to problems with responsiveness of some of these tests.<sup>21</sup>

Several single-item functional tests related to postural stability were developed for the frail elderly population but have been studied to various extents in a pediatric population. For the Functional Reach Test (FRT),<sup>111</sup> the individual is positioned with the shoulders perpendicular to a wall on which a yardstick has been affixed at shoulder level and is instructed to hold an arm out at 90 degrees of shoulder flexion. The individual is then asked to reach forward as far as possible without touching the wall or moving the feet. The length difference between the starting and ending reach positions is recorded. For children who are developing typically, measurements obtained with the FRT have demonstrated good reliability within a single session (ICC[2,1]=.98) and between

different days (ICC[2,1]=.75) as well as good intrarater and interrater reliability (ICC[2,1]=.83).<sup>112</sup> Two studies with small samples of children with balance dysfunction, however, showed poor test-retest reliability (ICC[2,1]=-0.31<sup>61</sup> and ICC[1,1]=.34<sup>113</sup>). Mean reach values and critical reach values (values that are two standard deviations below the mean) have been established for a group of children (N=101) between the ages of 5 and 15 years who are typically developing.<sup>112</sup> Scores below the critical value could indicate a problem with postural stability. Distances that children with disability have been able to reach appear to be different from those of children who are typically developing, demonstrating some construct validity.<sup>61,112,113</sup> Because of the good interrater reliability and the beginning normative data, we contend that the FRT can be used as a discriminative test. It also may be seen as a diagnostic test in terms of documenting, in general, problems with feed-forward control of postural stability. At this time, we do not recommend the use of the FRT as an evaluative measure in children due to the poor test-retest reliability with children with disabilities.

Another functionally based test, the timed "up and go" test,<sup>75</sup> consists of recording the amount of time required to rise from a chair, walk 3 m, turn around, return to the chair, and sit down again. Good interrater reliability (ICC[3,1]=.99) has been found with testing of children as a part of a study of correlation of balance tests.<sup>62</sup> Beginning data on results of this test in children with cerebral palsy show a correlation (Person  $r$  = .61-.95) with other assessments related to postural stability (P-CTSIB, FRT, PEDI-mobility, BOTMP-running speed), suggesting some validity to the test as a functional measure of postural stability.<sup>62</sup> This test also shows potential for differentiating between children with and without balance deficits and may, after test-retest examination, prove to be an appropriate evaluative measure.

The Functional Standing Test (FST) was developed to measure "functional standing" in children with spinal cord injury.<sup>114-116</sup> This test requires the child to stand at a station and perform upper-extremity tasks taken from the Jebsen-Taylor Hand Function Test<sup>117</sup> while maintaining postural stability in a standing position. The time it takes to perform each task is recorded. Interrater reliability studies on the FST in both adolescents who are typically developing and those with complete spinal cord injury showed moderate to good reliability (ICC=.60-1.00).<sup>116</sup> This test is a good candidate for an evaluative measure, in our opinion, but further research on test-retest reliability and validity is needed.

## Clinical Implications and Suggestions for Future Research

We have discussed the evaluation of postural stability from several perspectives and offered ways to classify current tests of postural stability. We believe that reliable and valid measures should be used to determine the contributing factors of our clients' postural problems so that we can design the most effective treatment possible. Following this, it is equally important to document the effectiveness of our treatment techniques. This is the only way in which we will transform our profession from an "art" to a "science" and be able to help our clients in the most effective and efficient manner.

The impairment dimension assessments of the three primary systems involved in the maintenance of postural stability—the sensory system, the motor system, and the biomechanical system—are administered primarily to identify problematic areas so that specific treatments can be prescribed. Although we have suggested splitting the construct of balancing into these three primary systems, we acknowledge that there are relational effects among these systems. Most children will have a combination of problems in these systems causing their difficulty with postural stability. For example, abnormal motor coordination may cause changes in the biomechanical capabilities of children with neurological deficits. Biomechanical abnormalities, however, may prevent "normal" coordination of postural motor responses and may alter sensory information, especially from the somatosensory system. By minimizing biomechanical abnormalities, the body may have the opportunity to select a more typical motor coordination pattern. To be able to assess these issues, more research is needed on the relationship between changing a child's ROM and force output and subsequent changes in motor coordination and sensory processing.

Therapists should monitor changes in impairments of these three systems over time and with treatment; however, interpretation of these changes needs to be considered carefully because, in general, the impairment dimension tests described have not demonstrated high test-retest reliability. This finding may be due, in part, to behavioral issues in testing children. It also may be due to the fact that children are developing and changing, which when added to the difficulty in controlling the external and internal environmental conditions between testing sessions, makes consistent measurement of postural stability difficult. There is need for further research to examine and improve test-retest reliability of assessments in all three systems. Although current tests can be suggested to have face validity and content validity, and in general have been shown to provide different results in children with and without disabilities, more validity research needs to occur related to the theoretical con-

structs of the testing and the relationship to other accepted criteria.

Sensory system measurement and test development related to isolating vestibular sensory problems have occurred in two camps: vestibulo-ocular and vestibulospinal. Based on the research to date related to problems with postural stability, we suggest that measurements be focused on postural reactions to altering sensory input rather than on vestibular-ocular testing. The available tests for examining sensory interaction for balancing are limited to either expensive laboratory posturography testing or the P-CTSIB. The P-CTSIB is limited to testing in a standing position and has only shown moderate test-retest reliability. More research to expand testing options of sensory systems and better develop the current methods of testing is needed.

Evaluation of the motor coordination of postural stability has been accomplished in the clinic through use of nonstandardized observations. Although a few tests have been developed, there is a need for more specific, reliable, and comprehensive motor coordination tests related to postural stability. Research using tests of motor coordination offer data on motor coordination during postural control, and these systems are becoming more available to practitioners. This type of testing is expensive, and how the detailed information can be used diagnostically to formulate treatment plans aimed at modifying timing, amplitude, and strategy selection for motor coordination remains unclear. Much research needs to be done in this area to understand the findings and to relate them to treatment techniques. Emphasis also needs to be placed on how these tests correlate with more functional tests of balance and on whether more clinically feasible and reliable observational mechanisms can be developed that provide the same information.

The biomechanical system represents the background on which we make our postural adjustments as well as our volitional movements; therefore, the biomechanical system needs to be included in evaluation and treatment of postural instability. Tests developed in this area are limited to measurements of maximal force and ROM and may not reflect the specificity of testing needed for this construct. Research is needed on development of the ability to maintain lower forces and critical values of ROM during tasks requiring postural stability.

When evaluating our clients' progress, we argue that it is not enough to change ROM or the ability to stand in altered sensory conditions in a laboratory or clinical setting. A change in postural stability during functional activities (ie, children's ability to move and interact in their everyday environment) must also occur. Therefore, we recommend also evaluating effectiveness of therapy

by assessment at the functional limitation dimension. Because there are only a few single-item functional tests directly related to postural stability and the current developmental and functional tests cover wide ranges of activities, development of more specific functional balance tests needs to occur. These “new” functional balance tests could also be focused on activities to obtain information about the three primary systems. For example, observing children doing a standardized set of activities such as lifting objects of known weight, running a distance, stair climbing, rising up on the toes, and so forth are general indicators of the presence of a minimal level of functional force production and could be scored for motor coordination patterns and adaptation to altered sensory surfaces. Results of this type of combined test development—measures of functional skills combined with impairment dimension measures—may begin to shed light on the critical values of force production, ROM, motor coordination, and sensory integration necessary for postural stability in normal activities.

In summary, there are some available reliable measures for evaluation of postural stability. Therapists need to attend to their theoretical view of the construct of postural stability, their objective of testing, and the qualities of the tool they are using. Research is needed for pediatric test and measurement development in all described areas related to postural stability.

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