Balance Retraining After Stroke Using Force Platform Biofeedback

Balance is a somewhat ambiguous term used to describe the ability to maintain or move within a weight-bearing posture without falling.[1,2] Balance can further be broken down into three aspects: steadiness, symmetry, and dynamic stability.[3] *Steadiness* refers to the ability to maintain a given posture with minimal extraneous movement (sway). The term *symmetry* is used to describe equal weight distribution between the weight-bearing components (eg, the feet in a standing position, the buttocks in a sitting position), and *dynamic stability* is the ability to move within a given posture without loss of balance.[3]

All of these components of balance (steadiness, symmetry, and dynamic stability) have been found to be disturbed following stroke.[2,4,5] Balance testing of patients with hemiparesis secondary to stroke has revealed a greater amount of postural sway during static stance,[1,4] asymmetry with greater weight on the nonparetic leg,[2,4] and a decreased ability to move within a weight-bearing posture without loss of balance.[2,4] Furthermore, research has demonstrated moderate relationships between balance function and gait speed (r=−.67 and .42, respectively),[6,7] independence (r=.62),[7] appearance (defined as "significantly abnormal," "slightly abnormal," and "nearly normal") (r=.50),[7] dressing (r.55–.69),[8] wheelchair mobility (r=.51),[8] and reaching (r=.49–.78).[9]

Thus, a principal construct within physical therapy practice is the reestablishment of balance function in patients following stroke. Recent advances in technology have resulted in the commercial availability of numerous force platform systems for the retraining of balance function in patient populations, including patients with stroke. These systems are designed to provide visual or auditory biofeedback to patients regarding the locus of their center of force (COF) or center of pressure (COP), as well as training protocols to enhance stance symmetry, steadiness, and dynamic stability. Typical force platform biofeedback systems consist of at least two force plates to allow the weight on each foot to be determined, a computer and monitor to allow visualization of the COF or COP, and software that provides training protocols and data analysis capabilities. Some units allow auditory feedback in addition to the visual feedback in response to errors in performance.

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Whether a platform system provides a COF measure or a COP measure is dependent on the strain-gauge setup within the force plates. Center of force is calculated only from the vertical forces projecting on the force plates. Center of pressure is calculated from both the vertical forces and the horizontal forces projecting on the force plates, thus accounting for horizontal shear. In the absence of postural sway, these two calculations are identical; however, when sway is present, they are similar, both allowing for the determination of symmetry, steadiness, and dynamic stability, but not identical.[10] For the purposes of this update, however, these two calculations will not be distinguished because many of the research publications do not provide sufficient detail to determine whether COF or COP was calculated.

Measures Used to Evaluate Balance Function and Progress

Three types of measures are most commonly used by force platform systems to evaluate balance function and patient progress related to balance ability: postural sway measures, symmetry measures, and limits-of-stability measures. Although each force platform system provides these measures in different units, they tend to provide a variant of each of these measures. Postural sway measures give information relative to postural steadiness; thus, a larger sway magnitude is related to greater postural unsteadiness. Sway measures include the sway area, sway path, and standard deviation or root mean square of the sway distance. The sway increase for patients following stroke has been reported to be as high as double that for age-matched peers.[7]

Symmetry measures reflect the amount of weight on each foot or the distance of the COF away from the midline. Testing of subjects following stroke has shown asymmetries in weight bearing of up to 27%, with control subjects demonstrating little asymmetry in weight bearing (ie, $<7\%$).[5]

Finally, most units provide a measure of dynamic stability related to limits of stability. The limits of stability are the maximal distance an individual can lean in any direction without loss of balance; these limits describe a cone projecting about the feet with maximal displacement equal to 8 degrees anteriorly, 4 degrees posteriorly, and 8 degrees laterally to either side.[11] Individuals with hemiparesis secondary to stroke have been found to have reduced limits of stability. Dettman et al[12] calculated a stability index (percentage of the base of support over which the COP was moved during weight shifting without loss of balance) as a measure of limits of stability for subjects with hemiparesis and age-matched control subjects. The stability index was 2.3% for the subjects with hemiparesis and 16.6% for the control subjects. The authors also reported that the COP was shifted toward the nonparetic limb in the subjects with hemiparesis.[12]

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Balance Retraining Protocols

Balance retraining with postural biofeedback can address each of the components of function described (steadiness, symmetry, and dynamic stability). Postural steadiness can be addressed through activities that require maintenance of the COF, usually depicted by the cursor on a computer screen, within a narrow target or within a narrow range, designated by a shaded area on the screen, as weight is transferred from one target to the next (Fig. 1).

Postural symmetry can be addressed by maintaining the COF in midline, defined on the computer screen by a vertical line or cross hair (Fig. 2), or by providing visual information regarding the percentage of weight on each foot or auditory input when less than a target weight is placed on the paretic limb. The patient can be asked to perform various activities while maintaining equal weight distribution, such as coming to a standing position or reaching.

Finally, dynamic stability can be addressed by activities that require weight shifting along the anteroposterior or mediolateral plane or to selected targets displayed on a computer screen (Figs. 3 and 4). These activities often address more than one balance component; activities that encourage stance symmetry also require minimal postural sway for the patient to be successful, and activities that involve weight shifting for dynamic stability also often address postural sway and symmetry in order for the target to be reached quickly and accurately.

Effectiveness of Postural Biofeedback

Steadiness

Numerous researchers have examined the effect of postural biofeedback on stance steadiness as measured by postural sway.[1,13–16] Only a few researchers, however, have studied this effect in individuals with hemiparesis.[1,13,15] Shumway-Cook et al[1] trained subjects to main-

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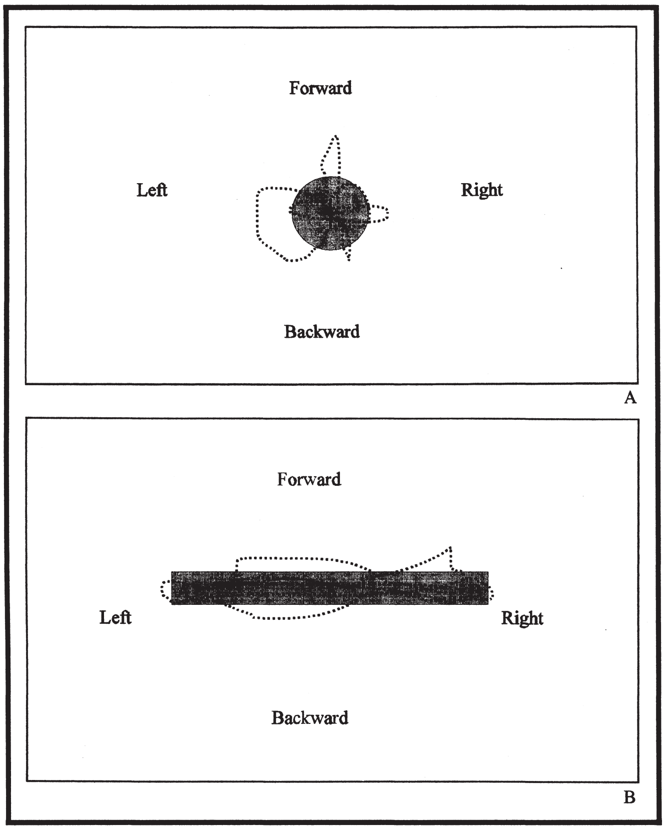

Figure 1.
Steadiness training with central target: (A) In this task, the subject is asked to maintain the computer cursor (central "+" sign) inside the shaded circle. The postural sway can be depicted on the screen as well (dotted line). Measures typically indicate the amount of time the cursor is maintained in the central target and the sway magnitude. (B) In this task, the subject is asked to shift weight repetitively from left (target A) to right (target B) while maintaining the cursor within the shaded rectangle; the sway can be depicted as well (dotted line). Time in the shaded area is calculated, as well as sway magnitude.

tain the cursor in the center of a small target in the middle of the computer screen with even weight distribution between the two feet. The emphasis of the training was on symmetry, but the activity required postural sway to be confined to the central target for the subject to demonstrate symmetry. There was no change in sway area following the 2 weeks of training for either biofeedback-trained or traditionally trained subjects, although symmetry was improved. Conversely, McRae et al[15] found a greater, but not statistically significant, decrease in postural sway in subjects trained with biofeedback in comparison with traditional therapy. However, the difference may not have reached statistical significance because of the small sample size; therefore, the results should be viewed with caution. Winstein et al[13] also reported a decrease in sway variability in subjects treated with postural biofeedback, but this decrease was equal to that of subjects treated by traditional physical therapy. Hocherman et al[17] examined the training effect of stance on a moving platform over time and found that subjects were able to tolerate increased amplitudes of

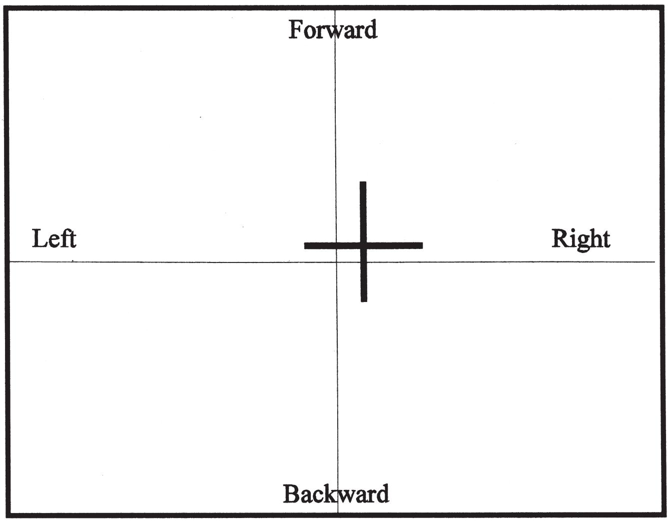

Figure 2.
Symmetry training with central target: In this task, the subject is asked to maintain the computer cursor (+) in the center of the computer screen as marked by the cross hair. The sway path may be depicted on the screen (not illustrated).

movement over the training period. This training effect might also be interpreted as increased steadiness, but these researchers did not use sway as a measure; instead, the measure used was the maximal platform movement tolerated without falling.

Symmetry

Most studies that have evaluated the use of postural biofeedback have emphasized stance symmetry in their training protocols. Symmetry has been addressed by providing feedback on the percentage of weight on the paretic limb[13,18] and by having subjects maintain a cursor in the center of a target on the computer screen.[1,19] In several studies, functional activities were incorporated into the symmetry training: coming to a standing position with equal weight distribution,[13,19] reaching to the side and returning to a symmetrical stance,[18] and stride standing and stepping.[13,19] In all of these studies, increased stance symmetry was found following training, and in those studies that had a control group, the increase in symmetry was greater in the subjects who received the biofeedback training than in the control subjects who received traditional physical therapy.[1,13,19] In addition, increases in symmetry have been reported to be maintained at a 1-month follow-up.[17] Furthermore, dynamic stability training, involving weight shifting to successive targets, has also been found to increase stance symmetry.[19]

Wannstedt and Herman[18] identified several other issues pertinent to the use of postural biofeedback training for enhancing stance symmetry. They reported greater improvement with this training in subjects with right hemiparesis compared with subjects with left hemipare-

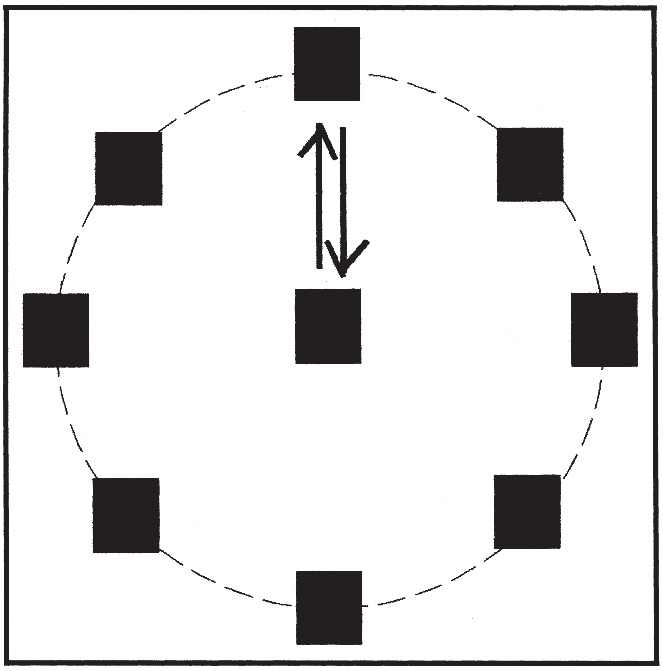

Figure 3.
Dynamic stability from center to target: A central target is surrounded by a series of targets. The subject is asked to move the center of force from the central target to a lit target and then back to the center within a given time period. Successive targets are then lit so that the subject has to shift weight successively in each direction. Transition time, path sway, and distance error can be calculated.

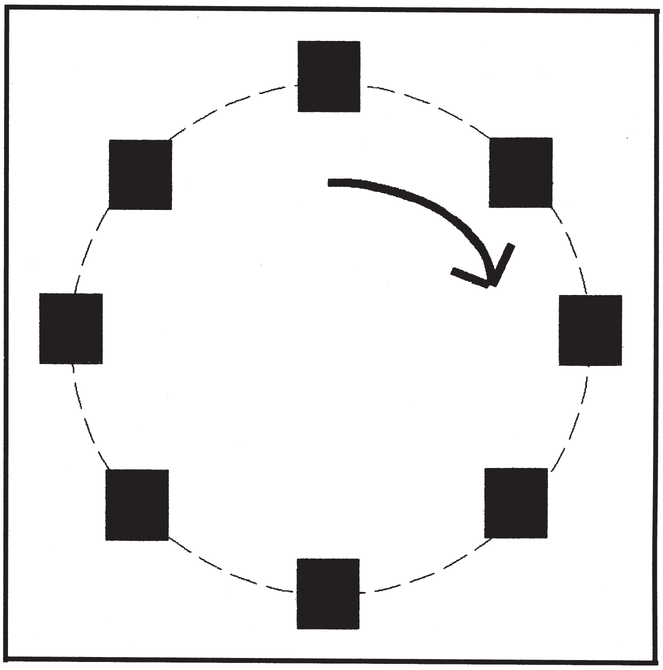

Figure 4.
Dynamic stability to successive targets: A series of targets in a circle are depicted on the computer screen. The subject starts at the uppermost target and has to transfer weight (depicted by the computer cursor) to each successive target as it is lit. This can be done in either a clockwise or counterclockwise manner. Transition time, path sway, and distance error can be calculated.

sis. This finding has not been addressed in any other study. They also reported that those subjects who were able to achieve symmetry in stance during the first training session with biofeedback were the only subjects to acquire the ability to maintain symmetry without feedback following their training protocol and to retain this ability 1 month later. Finally, the subjects in this study were all at least 6 months poststroke, which suggests that this type of training can be facilitatory even in persons with chronic strokes.

Dynamic Stability Training

The training of dynamic stability, referring to movement within the limits of stability, is most commonly done by having subjects shift weight so that the screen cursor, which is indicative of their COF, moves to a designated target. Two protocols have been described most consistently in the literature. One protocol involves a central target encircled by a series of targets at 45-degree angles (Fig. 3). The subject's task is to shift his or her weight forward to a lit target and back to the central target within a specified period of time, typically 7 to 10 seconds, before the next target is illuminated.[15,16,19] The transition time (time to move the COF from the starting position to the target), the sway path (cumulative distance covered), the sway error (accuracy of the weight shift from the central target to the peripheral target [calculated as a difference score: straight-line path − sway path]), and peripheral sway area (sway magnitude once the target is reached) are units used to evaluate patient performance.[20] The other protocol involves shifting weight around a series of successive targets oriented in a circle at 50% to 75% of the individual's limits of stability (Fig. 4); again, transition time, sway path, sway error, and peripheral sway area are the units used to evaluate subject performance.[14–16,19] This type of training has been found to decrease the magnitude of each of these variables, which indicates an increased accuracy of the weight shift in subjects without balance dysfunction,[13] older subjects with balance dysfunction,[16] and subjects with hemiparesis.[19] In addition, both subjects without balance dysfunction[14] and subjects with hemiparesis[16] have been able to extend their limits of stability with dynamic stability training. Expanding these limits should decrease the likelihood of falling, but this relationship has not been evaluated in any study. Furthermore, this type of training may affect steadiness. McRae et al[15] found a decrease in static sway following six dynamic stability training sessions in subjects with hemiparesis.

Although force platform measures of steadiness have been reported to be reliable and valid, units that use COF measures have been found to be more reliable than those that use COP measures (regression coefficients ranging from .31 to .85 for COF and from −.07 to .49 for

COP).[3] Furthermore, the dynamic measures (transition time, sway path, sway error) related to the dynamic stability activities have been found to be more reliable than static measures in subjects with hemiparesis (intraclass correlation coefficients ranging from .84 to .88 for dynamic measures and from .29 to .63 for static measures).[6]

Implications

Increased steadiness, decreased asymmetry, and enhanced dynamic stability are consistent with the therapeutic goals set for most patients with hemiparesis secondary to stroke. Thus, force platform biofeedback may be a useful tool in the treatment of these patients. The therapist designing a treatment protocol needs to keep in mind, however, that the evaluative measures, the type of training protocol used, and the therapeutic goals will have an impact on the effectiveness of this treatment modality.

I believe that the therapist needs to choose the best possible measure of patient progress. Steadiness, as measured by postural sway, has been found to be inconsistently affected by platform biofeedback. Of the studies that have examined sway following training,[1,13,15] two studies[13,15] demonstrated decreased sway and one study[1] demonstrated no change in sway. In the study by Winstein et al,[13] however, the magnitude of the decrease in sway was equal in the trained and nontrained subjects. Thus, biofeedback protocols may not be any more beneficial than traditional approaches in increasing postural steadiness but may add variability of practice to the treatment session.

Measures of symmetry and dynamic stability may, in my view, be more strongly linked to function and may be better indicators of patient progress than changes in postural sway or steadiness. Significant correlations have been found between these measures and improved transfer ability (Spearman correlations ranging from .34 to .54),[15] enhanced endurance (Spearman correlations ranging from .34 to .54),[15] and other measures of balance, including the Berg Balance Scale (Kendall coefficients ranging from −.55 to −.61)[6] and functional reach (Pearson correlation coefficients ranging from .66 to .75).[9] In two single-case studies, improved stance symmetry was associated with improvement in measures of activities of daily living and gross motor function.[19] Postural symmetry and dynamic stability also have consistently been improved by biofeedback training using force platform systems.[1,13–19] Furthermore, dynamic stability components (eg, transition time, sway error) have demonstrated better reliability than the static sway measures associated with steadiness.[6]

Although symmetry and dynamic stability have been found to correlate with many functional measures, the impact of platform biofeedback training on function is an area of considerable controversy in the existing literature. The degree to which postural biofeedback training seems to affect function appears to be related not only to the functional activity evaluated but also to the training protocol used.

Studies in which multiple activities were used, including a dynamic stability protocol, have shown the most consistent changes in patient function, including transfers,[15] home mobility (ability to move from one room to another),[15] endurance,[15] activities-of-daily-living scales,[19] gross motor function scales,[19] and gait.[16,19] Improvement in home mobility but not endurance was found in subjects following biofeedback training in comparison with a nontrained control group.[15] In an evaluation of two single-subject case studies, Sackley and Baguley[19] found substantial improvements in scores on the Rivermead Motor Assessment and a 10-point activities-of-daily-living scale with postural biofeedback that incorporated symmetry training in a standing position and in coming to a standing position, dynamic stability training to successive targets, reaching with a return to a symmetrical posture, stride standing and stepping, and bending the paretic limb while bearing weight on it. Subjects were tested over an 8-week period, using a reversal ABAB design. Improvements that were noted during the biofeedback training continued throughout the nontraining period. Thus, it appears to be important to include weight-shifting activities that challenge the limits of stability and require accuracy and speed within the retraining protocol to achieve functional improvement.

The most controversial aspect of postural biofeedback training has been its effect on gait. Although balance function and weight-bearing symmetry have been found to correlate with most gait components in subjects with hemiparesis secondary to stroke,[7] the effect of postural biofeedback on these gait components has varied considerably. In the earliest report of the effect of postural biofeedback training on gait, Winstein et al[13] identified increases in gait speed, cadence, stride length, and cycle time following biofeedback training, which were equal in magnitude to the changes identified for patients treated with traditional physical therapy, yet no change in the asymmetrical gait pattern occurred with either training protocol. More recently, McRae et al[15] reported that their nontrained subjects demonstrated greater improvement in ambulation than did subjects who trained with postural biofeedback; however, the method of evaluating ambulation was not described. In contrast, Rose et al[16] reported changes in joint angle diagrams and phase-plane portraits that reflected improved gait symmetry following balance retraining with a dynamic stability program in four subjects with hemiparesis secondary to stroke. This study, however, did not include a control group.

Thus, the type of training protocol (ie, static versus dynamic) may affect the transference of force platform biofeedback training to gait. Furthermore, improved gait symmetry has been reported with postural biofeedback during gait provided by a limb-load monitor.[21] These conflicting findings illustrate that the type of gait analyses conducted, the gait components chosen for analysis, and the training protocol used may affect the results. Moore and Woollacott[20] pointed out that studies have examined only time-distance or joint angle variables and that no studies have evaluated the magnitude of limb loading on the paretic limb. Future research, therefore, needs to address the effects of postural biofeedback training on components of gait not measured in the existing studies, such as limb loading, as well as evaluate the use of postural biofeedback during ambulation, which is possible with some commercially available units with a runway-type platform or movable footplates.

Finally, although there is considerable need for further research on the effects of force platform biofeedback on the balance components of steadiness, symmetry, and dynamic stability and its impact on functional outcome in patients with hemiparesis secondary to stroke, the research to date suggests that there is a place for this type of program in the rehabilitation of patients exhibiting postural asymmetry or decreased limits of stability following stroke. The patient's prognosis and therapeutic goals should define the role of postural biofeedback in his or her treatment program. For patients with more severe involvement, for whom postural steadiness sufficient for maintenance of stance is a primary goal, a training protocol that emphasizes postural steadiness may be sufficient; however, no research has been conducted with these types of patients. For patients with moderate involvement, for whom symmetry and dynamic stability in activities of daily living are goals, training protocols that address these postural components may be an appropriate component of the rehabilitation program and have been reported to enhance functional gains.[15,19] For patients with mild involvement, for whom symmetrical community-based ambulation is a goal, traditional force platform biofeedback may facilitate improvements in gait speed and cadence but may not address asymmetry.[13] Postural biofeedback with a limb-load monitor or force platform system that provides a runway, however, might facilitate symmetrical weight bearing during gait.[21]

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