Alterations in Weight-Transfer Capabilities in Adults With Hemiparesis

Background and Purpose. The purposes of this study were (1) to examine the position and displacement in the frontal plane of the body's center of mass (CM) with respect to the base of support during single-leg flexion movements in adults with hemiplegia and (2) to examine their relationship with other clinical scores.

Subjects. Fourteen ambulatory adult volunteers with hemiparesis of the right side of the body due to cerebrovascular accident participated in the study. Methods. Subjects performed single-leg flexion movements with the paretic and nonparetic limbs while standing on two separate force platforms. Motion analysis and force platform data were used to determine the displacement of the CM. Results. Successful performance of the transfer and holding single-limb stance occurred for 48% (to the nonparetic side) and 20% (to the paretic side) of the trials. Lack of success was due to insufficient displacement of the CM (26% of the trials to the nonparetic side and 17% of the trials to the paretic side) or a failure to maintain single-limb stance (26% of all trials to the nonparetic side and 63% of the trials to the paretic side). Overall, the final position of the CM with respect to the single-limb support region did not differ between sides. Successful performance was highly to moderately associated with clinical assessment scores for motor function and balance. Its association with gait velocity, however, was poor. Conclusion and Discussion. A classification scheme that can distinguish between four categories of bipedal to single-limb stance transitions has been established. Issues concerning clinical assumptions pertaining to the relationship between static and dynamic motor dysfunction in adults with hemiparesis are discussed. [Pai Y-C, Rogers MW, Hedman LD, Hanke TA. Alterations in weight-transfer capabilities in adults with hemiparesis. Phys Ther. 1994;74:647-659.]

Key Words: Hemiparesis, Human stance, Movement, Performance classification, Posture and balance.
considered major contributors to disordered hemiparetic gait.\textsuperscript{3-5}

Methods of improving posture, balance, and gait function among adults with hemiparesis have typically emphasized activities that facilitate weight bearing and weight transfer onto the involved lower limb.\textsuperscript{1,6-11} A prevailing assumption underlying such approaches is that improved symmetry of weight bearing during bipedal stance will result in improved balance and locomotor performance.\textsuperscript{3,8,11} A recent investigation,\textsuperscript{12} however, did not support the viewpoint that a reduction in limb-loading asymmetry results in improvements in hemiparetic gait. Such an observation raises the possibility that treatment strategies that rely on a static analysis of posture and balance function may not be optimally appropriate for dynamic activities in which significant accelerations of the body segments are occurring. Even quantitative measurements of quasi-static standing balance such as stance symmetry and center of pressure recordings collected via force platforms do not, therefore, necessarily characterize posture and balance performance during movement.\textsuperscript{14}

Emphasis on the analysis of movements that require dynamic weight shifting may provide clinicians with an improved understanding of the specific problems that can cause instability and falls in individuals with hemiparesis. Such information could also provide valuable directives for selecting the most appropriate therapeutic strategies.

Single-leg flexion, which includes intentional movement of one lower limb along with weight transfer to redistribute the body mass over the upcoming single-stance limb, is a desirable task to analyze in order to determine some of the problems individuals with hemiparesis have with transferring weight.\textsuperscript{15} There are similarities between leg flexion and gait with respect to the lateral transfer of the body's center of mass (CM) from bipedal to unipedal stance\textsuperscript{16} and in achieving single-limb support of the body mass.\textsuperscript{17} Motion of the CM in the frontal plane is especially relevant for persons with hemiparesis who exhibit instability in this direction, instability that has been considered a major cause of falls toward the affected side of the body.\textsuperscript{18} By abruptly reducing the standing base of support from a larger (bipedal) to a smaller (unipedal) area, the balance control system may be substantially challenged. Because the weight-transfer component of moving from bipedal to single-limb stance is a preparatory postural response, leg flexion is normally executed without focusing one's attention on the dynamic transition in stance support.

Recent studies\textsuperscript{15-16,19} have demonstrated alterations in the normal spatial and temporal characteristics of lateral horizontal ground reaction force (GRF) (the contact force between the lower limbs and the support surface while standing) measurements underlying transitions in stance during single-leg flexion movements in a sample of subjects with hemiparesis. Overall, differences in actively generated kinetic responses recorded separately beneath the paretic and nonparetic lower limbs indicated highly significant reductions in the magnitude of force contributed beneath the paretic and nonparetic lower limbs indicated highly significant reductions in the magnitude of force contributed beneath the paretic limb to the overall GRF acting to initially propel the CM laterally. This observation applied whether the paretic limb served as the upcoming flexing limb or the base of support during single-stance limb. Consequently, dynamic transitions in stance support may be affected regardless of whether subjects with hemiparesis direct weight transfer toward the paretic or the nonparetic side of the body.

Although information derived from a kinetic analysis of dynamic transitions in stance provides insight into specific problems that some individuals with hemiparesis may have during goal-directed tasks, the functional outcome of such changes in terms of the actual movement characteristics of the CM remain to be evaluated. For example, it is unclear whether difficulties in executing weight transfer during leg flexion are associated with changes in the normal displacement of CM during the transfer phase or with difficulties in maintaining the final location of the CM position after the dynamic transition. Each of these possibilities offers potentially different directives for selecting the most appropriate treatment strategy for addressing alterations in posture and balance function among adults with hemiparesis.

The purposes of this study were (1) to examine the position and peak displacement in the frontal plane of the body's CM with respect to the base of support during single-leg flexion movements performed by adults with hemiparesis due to CVA and (2) to examine their relationship with other clinical scores. Based on clinical observations and previous analyses of GRF measurements, we hypothesized that subjects would demonstrate a variety of performance outcomes that could be classified according to four different categories as follows: (1) successful completion of weight transfer and maintaining the CM within single-limb base of support for a minimum of 2 seconds (success), (2) failure to maintain weight transfer (failure to hold), (3) insufficient transfer of weight such that displacement of the CM never reached the unipedal base of support (undershoot), and (4) excessive transfer of weight in which displacement of the CM exceeded the single-limb base of support (overshoot) (Fig. 1). We also predicted differences in performance outcomes pertaining to weight-transfer ability that would depend on the intended direction of lateral motion of the body's CM.

**Method**

**Subjects**

Fourteen adult volunteers (6 female, 8 male), ranging in age from 19 to 73 years (X=52.6, SD=15.0), participated in the study. Subjects were diagnosed at least 6 months prior to testing as having had a single cerebral ischemic infarction with residual hemiparesis of the right side of the body. This
The position of the feet was traced on the platforms to ensure consistent foot placement over trials.

Following a command from the experimenter, subjects flexed the designated lower limb from the support surface at their natural (preferred) speed until the foot just cleared the floor, and they were instructed to maintain that posture for the duration of the 5-second trial. No external support was provided to the subjects to accomplish the leg flexion task. Blocks of five trials were performed for each limb, with the order of presentation of right-versus left-leg flexion rotated across subjects. Overall, the movement series took approximately 20 minutes to complete.

A WATSMART® motion analysis system was used to record the instantaneous frontal-plane locations of approximate joint centers at the ankles, knees, hips, and shoulders during the performance. Infrared light-emitting diodes (LEDs) were taped onto the skin overlying these body landmarks, which faced two infrared cameras placed 3.5 m from the subject. A personal computer was used for the motion analysis data collection, and a PDP 11/73 computer was used to collect the force platform data. The two computers were synchronized by an input trigger signal from the kinematic data collection system to the kinematic data collection system. For each trial, data were sampled at a rate of 100 Hz for a 5-second period.

**Data Processing**

The coordinates of the body segment landmarks derived from the WATSMART system were smoothed using a low-pass second-order Butterworth digital filter at a cutoff frequency of 3 Hz. The instantaneous location of the CM of each segment and its mass were estimated based on segment characteristics. This information was used to compute the position of the CM of the total body. The feet position traces were used to determine the CM projection with respect to the base of support.

Footprint length of the feet. The position of the feet was traced on the platforms to ensure consistent foot placement over trials.

Individuals with identified subcortical lesions or involvement of the brainstem were excluded from participation. Additional exclusion criteria included the following: spatial-perceptual or visual field deficits; a score of less than 6 out of 12 on the lower-limb sensation portion of the Fugl-Meyer assessment (except for one subject for whom data were unavailable); and other significant neurological, musculoskeletal, or general medical problems as determined by medical records and self-reports.

Subjects were required to be able to stand and perform voluntary combined hip, knee, ankle flexion movements with either leg without the aid of orthotic devices or other external support. All participants were independent ambulators, as indicated by their ability to walk without the physical assistance of another individual. A standardized clinical evaluation using the Fugl-Meyer assessment of physical performance for lower-extremity motor function and balance was administered by one of the investigators (LDH or TAH) prior to testing. Maximum walking velocity was measured with a stopwatch while the subjects walked 7.62 m (25 ft), with the aid of assistive devices where applicable. Informed consent was obtained from all subjects.

**Procedure**

Participants stood with arms folded at waist level and the feet positioned on two separate strain-gauge force platforms as parallel as possible while they assumed a self-selected weight-bearing posture. The width of the base of support was standardized with respect to each subject's foot length by having the distance between the midpoints of the heels equal to the

**Figure 1.** Deterministic model for performance outcomes associated with weight transfer in the frontal plane accompanying transitions from bipedal to single-limb stance during leg flexion movements.
An undershoot was indicated when the peak displacement of the CM never reached the base of support of the limb used during single-leg stance. An overshoot was indicated by a displacement of the CM that exceeded the lateral border of the single-limb base of support during the transfer. Each unsuccessful trial was confirmed by the force platform recordings, which showed the subsequent contact(s) of the flexing limb after leaving the platform.

The displacement-time history of the CM was used to identify the onset and termination of dynamic transition of the CM projection within the single-limb stance support boundaries. The onset of dynamic transition can be represented by an abrupt change in CM position, and the termination of the transition is associated with the first peak in CM displacement followed by a regularly fluctuating waveform within a narrow range associated with single-limb stance, or by returning of the CM toward the initial bipedal standing position as in the case of the undershoot trials. The location of the CM at the termination (L' in Fig. 2) was considered to be the final position of the transfer. The width of the foot (distance L in Fig. 2) was the distance between the medial border and the furthest point of the lateral border of the single-limb stance foot. The final position was expressed as a percentage of the width of the foot associated with the unipedal base of support (L'/L×100%).

Data Analysis

The group means, standard deviations, and ranges of the CM final position measurements over all trials were obtained. Separate subject × trial two-way analyses of variance (ANOVA)s and separate intraclass correlation coefficients (ICCs) were performed to determine the reliability of the data using the SYSTAT statistical package. The ICC (2,1) as described by Shrout and Fleiss was utilized.

The frequency of each performance outcome was determined and compared between the two sides using a
Table 1. Group Means, Standard Deviations, Ranges, and Intraclass Correlation Coefficient (ICC[2,1]) Reliability Estimates of Body's Center of Mass Peak Displacement (in Meters) in the Frontal Plane Relative to Single-Limb Support Region During Bipedal to Single-Limb Transitions (N=14)

<table>
<thead>
<tr>
<th>Nonparetic (Left) Limb</th>
<th>Parietic (Right) Limb</th>
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<tbody>
<tr>
<td>X</td>
<td>SD</td>
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<tr>
<td>0.025</td>
<td>0.028</td>
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*Negative displacement values indicate distance from medial border of single-limb stance foot in the direction of the flexing limb.

chi-square test. A one-way ANOVA was used to examine possible differences in the group mean final position of the CM as a function of the side used during single-limb stance. The Spearman rho correlational analysis was used to evaluate the relationship between dynamic performance outcome measures and Fugl-Meyer performance scores. A significance level of .05 was adopted for all statistical comparisons.

Results

Reliability of Measurements

Eleven of the 140 recorded trials for kinematic data (14 subjects×5 trials×2 sides) were missing due to accidental blockage of the ILEDs during the experiments. Separate subject×trial ANOVAs for right- and left-limb stance indicated significant between-subject effects (P<.05) and nonsignificant subject×trial interactions (P>.05). Such effects are prerequisites for the ICC to be useful in representing reliability. The ICC value for paretic-side (right-limb) stance was .68, whereas the ICC value for nonparetic-side (left-limb) stance was .86 (Tab. 1).

Outcome of Performance

Data from representative trials that resulted in success, failure to hold, and incomplete transfer are shown in Figure 3. Interestingly, the displacement of the CM never exceeded (overshot) the widest point of lateral border of single-limb support in our sample of subjects.

The results of individual trials in which the subjects performed the leg flexion task involving weight transfer from bipedal to single-limb stance are presented in Table 2. As indicated in Figure 4 and revealed by the highly significant chi-square test (X²=18.4, P<.001), the outcome of performance was clearly dependent on the direction of the CM displacement. When the nonparetic (left) limb was used in single-limb stance, close to one half of the total trials were successful. One half of the trials in left-limb stance were unsuccessful due to incomplete transfers, and the other half were unsuccessful due to failure to hold the single-limb stance after the completion of the CM transfer. When the direction of the CM displacement was reversed toward the paretic side, only one fifth of the total trials were successful. In this case, the primary reason for unsuccessful performance was failure to hold the paretic-side (right) single-limb stance.

Final Position of the Center of Mass With Respect to Base of Support

The group mean locations of the CM at the termination of the transfer normalized to the width of the foot used during single-limb stance were 19.83% (range= -28.30% to 61.47%, SD=25.01%) for transfers to the nonparetic limb and 28.02% (range= -3.96% to 69.08%, SD=21.26%) to the paretic limb.

Interestingly, significant differences in the final position of the CM attributable to the side used during single-limb stance were not observed (F=0.87; df=1,26; P>.05). Furthermore, successful transfers were not associated with displacement of the CM to the center of the support region, but rather corresponded to about one third of the width of the single-limb support region (38.3%) close to the medial border of the foot.

Relationship Between Performance Outcome and Clinical Assessment

The number of successful trials and the Fugl-Meyer assessment scores for lower-extremity motor function and balance, in addition to walking velocity recorded over 7.62 m, are presented in Table 3. The rank order of subjects' performance outcomes according to the total number of trials classified as successful and the rank orders for the clinical assessment components are presented in Table 3. Relationships between performance outcomes associated with lateral weight-transfer function and Fugl-Meyer assessment scores were moderately high for lower-extremity motor function (rho=.81, P<.0025) and moderate for balance function (rho=.63, P<.05). In contrast, the lowest degree of relationship (rho=.40, P<.10) was between successful performance of weight transfer and maximum walking velocity over 7.62 m.

Discussion

Reliability of Measurements of Weight-Transfer Function

Inconsistency of a measurement may be attributable to instrumentation error, tester error, or variability in subject performance. Examination of the validity and reliability of the measurement system used in this study has indicated that error attributable to the instrumentation is minimal. Similarly, the use of operational definitions of the kinematic events under investigation in conjunction with graphical analysis programs used to
identify and quantify performance outcomes minimizes potential error introduced by the experimenter during analysis. Therefore, the variance of the ICC values in our study was predominantly attributable to the variability in subject performance.

It is noteworthy that although overall measurements of performance outcome were moderately (ICC = .68) to highly (ICC = .86) consistent, kinematic response measurements were less consistent for CM displacements toward the paretic side of the body. This result resembled a similar observation of more variable measurements of upper-limb muscle activation patterns and isometric torque production for the paretic arm versus the nonparetic arm in adults with hemiparesis. It may be that in addition to improvements in mean performance outcome for a given measurement, an improved consistency of measurements of outcome may be a useful index of treatment efficacy.

Performance Outcomes

Examination of the outcome of each trial revealed several characteristics of weight-transfer function in the frontal plane during transitions from bipedal to single-limb stance support accompanying voluntary leg flexion movements. A striking, though not surprising, feature was that the success rate of performing the task was much greater when the nonparetic leg served as the base of support during single-limb stance. Thus, successful performance among our sample of adults with hemiparesis was about 2½ times greater when transfer was directed toward the nonparetic versus the paretic side of the body.

Although this finding was compatible with routine clinical impressions, the results also indicated successful performance of lateral weight transfer toward the nonparetic side for only 48% of the total trials. To our knowledge, these are the first objectively documented measurements that indicate major alterations in weight-transfer ability toward the "unaffected" side of the body in a sample of adults with hemiparesis. The results

Figure 3. Examples of three types of performance outcome in leg flexion involving bipedal to unipedal transfer: (a) success, (b) failure to hold, and (c) insufficient transfer (undershoot). Top record in each example is the body's center of mass (CM) displacement-time history in the frontal plane, and the two dotted lines indicate the borders of the base of single-limb support region in a medial-lateral direction. The middle and bottom records, respectively, correspond to the vertical ground reaction force registered beneath the stance and flexing limbs.
Table 2. Individual Trial Outcomes of Weight Transfer During Leg Flexion Movements Involving Transitions From Bipedal to Single-Limb Stance Onto the Nonparetic Limb (n=65) Versus the Paretic Limb (n=64) in Hemiparetic Adultsa

<table>
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<tr>
<th>Number of Trials for Each of Three Types of Outcome</th>
<th>Successful Transfer and Hold</th>
<th>Failure to Hold</th>
<th>Insufficient Transfer (Undershoot)</th>
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*Note: Trials resulting in overshoot performance did not occur.

are also compatible with earlier observations of changes in normal GRF patterns underlying transitions in stance following stroke.

It should be emphasized that our sample of subjects was representative of individuals with rather high levels of functional capacity, as indicated by their scores on the Fugl-Meyer functional assessment test and general level of locomotor ability. All subjects were independently ambulatory (some with the assistance of canes or ankle-foot orthoses) in that they did not require the contact assistance of others. Despite such a relatively high level of function, significant difficulties were encountered when subjects attempted to negotiate transitions from bipedal to single-limb stance support in conjunction with leg flexion movements performed with either the paretic lower limb or the nonparetic limb.

Whereas unsuccessful trials involving weight transfer to the nonparetic limb were equally attributable to insufficient transfer of the CM and a failure to hold the final position of the CM, unsuccessful attempts toward the paretic side of the body were predominantly due to a failure to maintain the CM within the single-limb base of support. For trials with insufficient transfer, the duration of single-limb stance was very brief (eg, Fig. 3c). In such cases, the rotational effect produced by the subject's weight produced a tendency to fall back toward the flexing limb as it rapidly contacted the ground.

Uncompleted transfer due to undershoot could have been caused by an insufficient initial propulsive impulse (ie, the net effect of force acting over a period of time) generated beneath the upcoming flexing paretic limb or by inadequate reduction of the initial resting lateral horizontal force beneath the stance limb that normally opposes the intended direction of the weight transfer. Either or both of these factors may have prematurely terminated the weight transfer.16 In contrast, failure to hold the final position of the CM may have been attributable to inadequate or inappropriate fine adjustments in GRFs, possibly due to altered joint torques at the hip or ankle of the lower extremity used during single-limb stance.26
Table 3.  Actual Scores and Spearman's Rank Scores for Trial Performance, Fugl-Meyer Assessment Scores for Lower-Limb Motor Function and Balance, and Ambulation Velocity (in Meters Per Second)\textsuperscript{a}

<table>
<thead>
<tr>
<th>Subject</th>
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\textsuperscript{a}Ranks in columns M, B, and V correspond to rank of trial performance associated with the Spearman's rho correlation for lower-limb motor function (M), balance (B), and ambulation velocity (V), respectively. A given subject's rank for trial performance may differ for each correlation due to different number of subjects for each correlation. Score range: lower-limb motor function=0-34; balance=0-14.

Failure to maintain quasi-static single-limb stance might also have been a consequence of inadequate antigravity support against collapse with respect to the vertical direction.\textsuperscript{27}

None of the subjects transferred their CM beyond the widest point of the outer (lateral) edge of the single-limb stance base of support during the dynamic movement phase of the weight transfer. This outcome has the potential danger of producing a fall toward the paretic side of the body, a common occurrence among individuals with hemiparesis due to stroke.\textsuperscript{18,28,29} Due to the width of the forefoot being greater than the width of the heel region, it is possible that the subjects' CM may have traveled beyond the lateral edge of the single-limb base of support at a point at which the width of the foot is narrower than at its point of maximum width. Loss of equilibrium, requiring external assistance or protective balance responses such as steps or hops associated with such a possibility, did not occur.

The lack of exceeding the absolute limit of the target location of the unipedal base of support area may have been related to the speed of leg flexion. Thus, subjects may have selected a speed at which they were able to safely control their total body motion by not exceeding the terminal mechanical constraints on balance represented by the single-limb base of support. We have observed numerous instances of loss of equilibrium among subjects with hemiparesis when leg flexion movements were executed "as fast as possible." Rapid speeds of movement are, therefore, likely associated with greater internally generated disturbances to balance while standing than are movements performed at relatively slow speeds.\textsuperscript{30}

Relationship Between Final Center of Mass Position and Base of Support

For successful transfers, the CM was displaced to the region along the medial border of the single-limb stance foot. This finding is similar to what occurs during human gait when the CM projection normally moves along the medial border of the foot during the single-limb support phase.\textsuperscript{14} Similarly, trials that resulted in a failure to hold the position of the CM within the base of support were indistinguishable from successful trials with respect to the peak displacement of the CM during the movement phase of the weight transfer. This finding indicates why there were no differences between sides of the body for normalized measurements of CM displacement. Though subjects showed significantly fewer successful trials when transferring weight toward the paretic versus the nonparetic side, this difference was primarily attributable to a failure to hold the position of the CM rather than to how far the CM was displaced during the movement phase of the task. In trials in which the CM did not reach the base of support area (undershoot), the shorter excursion associated with such trials indicated that subjects did not accomplish the necessary postural prerequisite (ie, weight transfer) to performing the goal-directed task of...
lifting and holding the leg from the ground.

**Relationship Between Performance Outcome and Clinical Assessment**

The results of the rank-order analysis relating trials with successful performance outcome and Fugl-Meyer assessment scores for balance and lower-extremity motor function indicated that the clinical assessments were moderately to highly associated with the subject's ability to perform lateral weight transfer. The quantitative observations recorded in this study indirectly support the validity of the clinical evaluation tests and suggest that these tests may provide a useful means for predicting an individual's sensorimotor function for tasks that are beyond the scope and generally static nature of the actual Fugl-Meyer assessment protocols.

Despite the fact that transitions from bipedal to single-limb support are a necessary prerequisite to the initiation and ongoing execution of human gait, as well as standing leg flexion movements, the data indicated a weak relationship between speed of walking over 7.62 m and precision of controlling movement of the CM in the frontal plane. Several possibilities may have accounted for this outcome. First, we did not evaluate temporal measures of weight-transfer dynamics, which may have revealed an improved correspondence with gait speed. Second, the physical constraints of the walking test differed from those imposed on the leg flexion task. Subjects were requested to walk the required distance “as fast as possible,” either with or without the use of canes or ankle-foot orthoses. Thus, the observed qualitative aspects of gait were highly variable among subjects. In contrast, leg flexion was performed at natural, self-selected speeds of movement without assistive devices or orthoses and may have represented a relatively novel motor task in comparison with the more well-practiced act of gait. Third, although leg flexion and gait share the requirements of limb withdrawal and weight transfer, the CM does not have to be maintained within the single-limb base of support during gait as it does for leg flexion. A falling back toward the flexing swing limb normally occurs after single-limb support has been briefly established in walking.14

Despite overall task differences, however, we have observed GRF profiles underlying the propulsive phase of lateral weight transfer during gait initiation to be essentially identical to GRF patterns that accompany leg flexion movements.16 There are no definitive reasons why similar processes at the kinetic level are not, at least in part, normally used during the ongoing execution of human gait.

**Clinical Evaluation and Treatment**

The findings of this study have implications for several areas related to clinical practice. A valid, reliable, and objective classification scheme for assessing weight-transfer function in the frontal plane has been provided. The validity of this scheme is based on a fundamental biomechanical principle underlying the maintenance of stationary upright stance, whereby the CM projection has to remain within the base of support regardless of whether bipedal or single-limb stance is achieved. Differences in performance outcomes, ranging from success to insufficient transfer to failure to hold the transfer, indicated specific differences among individuals with hemiparesis due to CVA in their ability to control motion of the body's CM during a voluntary leg movement task.

Although routine clinical measurements using such a motion analysis system are generally not, at present, feasible due to the cost and technical nature of the instrumentation, such an approach may provide valuable directives in identifying the nature of disordered weight-transfer ability. Such information should in turn facilitate the development of treatment approaches that are founded on knowledge of patient-specific problems rather than on uniform assumptions about weight bearing and weight-transfer function among adults with hemiparesis. For example, the finding that failure to achieve successful weight transfer onto the paretic side during single-limb stance was primarily attributable to a failure to maintain the final position of the CM is in contradiction to the clinical assumption that persons with hemiparesis are generally unable to shift their CM far enough onto the paretic limb.6,7,11

Although subjects were more successful in accomplishing transitions in stance toward the nonparetic versus the paretic side of the body, over 50% of the trials involving weight transfer to the nonparetic side were unsuccessful. In light of this finding, clinical procedures that routinely emphasize increased weight bearing on the paretic limb and weight transfer toward the paretic side should be expanded to include dynamic transitions in stance toward the nonparetic limb. Such emphasis may be particularly important because approximately 80% of the total horizontal GRF acting to propel the body in the frontal plane during leg flexion and other tasks is normally generated beneath the limb opposite the intended direction of weight transfer16 (ie, beneath the flexing limb). Much of the propulsive force is normally attributable to actively generated hip abductor torque of the flexing limb.31 The proposed dynamic role for hip abductor musculature (eg, gluteus medius) in contributing to the initiation and execution of the weight transfer is in addition to its known static role in stabilizing the pelvis during single-limb stance.32,33 Therefore, important challenges to the paretic flexing limb generally, and hip abductor musculature specifically, may be afforded by emphasizing transitions in stance toward the nonparetic side as well as toward the paretic side of the body.

As noted previously, the initial propulsion of the CM requires the active generation of lower-limb joint torques, which results in changes in the resting GRFs acting on the body in order to set it in motion. Subse-
quently, the momentum of the body must be reduced to safely achieve single-limb stance, or subjects would likely exceed the outer limit of the unipedal base of support. Consequently, even though subjects may be able to maintain quasi-static single-limb stance following an assisted weight transfer, they may be unable to independently perform the necessary dynamic transitions from bipedal to unipedal stance. Therefore, physical therapy evaluation and treatment strategies that emphasize static postures (eg, maintenance of single-limb stance) and performance measures (eg, symmetry of standing weight distribution), may have little bearing on dynamic motor deficits (eg, transitional phase of weight transfer, dynamic balance control, gait) in hemiparesis.

Finally, emphasis on task dynamics by having subjects perform very rapid as opposed to slower transitions in stance may be a more sensitive probe for distinguishing between deficits in balance control and problems in propelling total body motion. Similar speed-related challenges to movement should also be incorporated into treatment because it has become increasingly apparent that rapid speeds of movement for a variety of tasks may be normally controlled very differently than when the same task is executed at appreciably slower speeds. Observations underscore the need to reexamine clinical assumptions pertaining to the relationship between quasi-static and dynamic movement dysfunction in adults with hemiplegia.

Conclusions

Subject-specific differences in performance outcomes associated with weight-transfer ability in the frontal plane during a voluntary leg flexion task were observed. Failure to maintain single-limb stance at the termination of the CM displacement was the primary reason for lack of success for transfers to the paretic side, where 80% of the trials were unsuccessful. Transitions in stance to the nonparetic side were unsuccessful for 52% of the trials and were equally attributable to failure to hold the final position of the CM and insufficient displacement. Overall, the findings indicated an objective, valid, and reliable means for measuring performance outcomes related to balance function following CVA. The findings further underscore the need to reexamine clinical assumptions pertaining to the relationship between static and dynamic motor dysfunction in adults with hemiparesis.

Acknowledgments

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References

8 Wannstedt GT, Herman JBiomech. 1979;86:151-152.
30 Lee WA, Buchanan TS, Rogers MW. Effects of arm acceleration and behavioral conditions on the organization of postural adjustments.
Pai and colleagues have shown that ambulatory individuals with a left cerebrovascular accident (CVA) are capable of the leg-flexion/frontal-plane weight-transfer task to the nonparetic limb 48% of the time and to the paretic limb only 20% of the time. They also characterized the nature of the failed trials to the nonparetic side as a failure to hold (26%) or a failure to accomplish the necessary displacement of the center of mass (CM) (26%). To the paretic side, failures were primarily due to an inability to hold (63%), whereas only 17% of the failures were attributed to a lack of adequate CM displacement. The authors should be commended for a well-done study that provides sound baseline information on voluntary dynamic weight-transfer capability. In addition they have provided a potentially useful classification scheme for evaluation and clinical decision making. This commentary is focused on two important issues. First, do the measures used (ie, CM position and displacement) provide insight into the motor control deficit? Second, can the results be generalized for individuals with stroke?

The authors provide a convincing rationale for the use of a dynamic task to evaluate weight-transfer capability. With respect to evaluation and treatment, they state that "treatment strategies that rely on a static analysis of posture and balance function may not be optimally appropriate for dynamic activities in which significant accelerations of the body segments are occurring." It therefore seems surprising that they used static measures of CM position and displacement to evaluate capability in this arguably dynamic task. It would be potentially more informative to quantify the displacement-time history (ie, the rate of change of CM displacement or force). Visual examination of Figure 3 suggests that the rate of change of force may be predictive of (or at least correlated with) CM-displacement and weight-transfer success. Previous work\(^1\)\(^—\)\(^3\) suggests that such dynamic measures can be more useful than static measures in characterizing motor control deficits of disordered movements. The static measures used seem to have been chosen to specifically address the question: Does the CM move too far or far enough, and can its position be maintained? Perhaps a more interesting question is: What is the nature of the CM movement in this dynamic weight-transfer task, and is it predictive of task success?

The authors have the data for such analyses, and I would be interested in knowing the answers to the following questions: (1) Is the peak force (generated by each limb) correlated with the initial rate of change of CM position and with task success? and (2) Is the peak velocity or acceleration of CM displacement correlated with task success? One working hypothesis is that if the dynamics of change of CM position are inadequate, the transfer is not successful. Further, if the electromyographic activity generating the force for CM displacement is poorly timed or scaled, the dynamics of CM displacement would be similarly affected.

The data presented in Figure 3 suggest in general that the motor program (ie, the initial pattern of CM or force change) for weight transfer is intact, but the capability to appropriately scale it to meet task demands may be poor. This interpretation is consistent with previous work\(^4\)\(^—\)\(^3\) using rapid aiming movements in individuals with stroke where the selection of the appropriate motor program is intact, but the capability to scale the program in amplitude is particularly problematic in individuals with stroke compared with age-matched controls.

The second issue of concern deals with the generalizability of the findings to individuals with a right CVA of equal severity. The inclusion criterion of Pai and colleagues (ie, only individuals with a left-hemisphere cerebral ischemic infarction) was an attempt to minimize the existence of spatial-perceptual deficits associated with lesions of the nondominant hemisphere. It is true that the right hemisphere of most right-handed individuals (96%) is specialized for spatial-perceptual processing; however, equally important is that the left hemisphere of most right-handed individuals is specialized for precise temporal sequencing of complex programmed actions such as speech and goal-directed aiming.\(^5\)\(^—\)\(^7\) Also, it has re-