ORIGINAL ARTICLE

Determinants of Limb Preference for Initiating Compensatory Stepping Poststroke

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ABSTRACT. Mansfield A, Inness EL, Lakhani B, McIlroy WE. Determinants of limb preference for initiating compensatory stepping poststroke. Arch Phys Med Rehabil 2012;93: 1179-84.

Objective: To investigate the determinants of limb preference for initiating compensatory stepping poststroke.

Design: Retrospective chart review.

Setting: Inpatient rehabilitation.

Participants: Convenience sample of individuals admitted to inpatient rehabilitation with poststroke hemiparesis.

Interventions: Not applicable.

Main Outcome Measures: Compensatory stepping responses were evoked using a lean-and-release postural perturbation. The limb used to initiate compensatory stepping was determined. The relationships between stepping with the paretic limb and premorbid limb dominance, weight bearing on the paretic limb in quiet standing, ability to bear weight on the paretic limb, preperturbation weight bearing on the paretic limb, and lower-limb motor recovery scores were determined.

Results: The majority (59.1%) of responses were steps initiated with the nonparetic limb. Increased lower-limb motor recovery scores and preperturbation weight bearing on the nonparetic limb were significantly related to increased frequency of stepping with the paretic limb. When the preferred limb was physically blocked, an inappropriate response was initiated in 21% of trials (ie, nonstep responses or an attempt to step with the blocked limb).

Conclusions: This study reveals the challenges that individuals with poststroke hemiparesis face when executing compensatory stepping responses to prevent a fall after a postural perturbation. The inability or challenges to executing a compensatory step with the paretic limb may increase the risk for falls poststroke.

Key Words: Biomechanics; Paresis; Postural balance; Rehabilitation; Stroke.

RAPID CORRECTIVE reactions are essential to regain stability and prevent a fall after a postural perturbation.[1] Compensatory steps, which increase the size of the base of support, are a particularly important type of balance-recovery reaction.[1] Such change in support reactions are the preferred response to a loss of balance,[2,3] and the final defense to prevent a fall.[3] Compensatory stepping reactions are characterized by: (1) extremely rapid onset and movement speed,[4] (2) amplitude and trajectory scaled to the degree of instability,[3] and (3) ability to accommodate environmental circumstances.[5] These characteristics place tremendous demands on those with stroke, potentially increasing the risk for falls.

A unilateral focal stroke typically results in contralesional sensorimotor impairment, which leads to asymmetry in performance of functional activities.[6] This functional asymmetry presents a challenge for the control of compensatory stepping: an individual with hemiparesis poststroke must rely on the paretic lower limb for either initiating the response or accepting weight to initiate a step with the nonparetic limb. Previously, we observed that when young healthy individuals stand asymmetrically, they will initiate compensatory stepping with the less-loaded limb.[7] However, in a pilot study we observed that individuals with stroke tended to initiate compensatory stepping with the nonparetic limb despite bearing more weight on that limb.[8] Unloading the nonparetic limb prior to rapid stepping takes extra time, which may compromise stability. When stroke patients' nonparetic limb was physically blocked with an obstacle, they continued to attempt to initiate stepping with that limb,[8,9] further demonstrating reluctance to step with the paretic limb. The desire to step with the nonparetic limb, regardless of environmental constraints, may reflect challenges in the ability to rapidly execute and accurately place a step with the paretic limb due to limb-specific sensorimotor impairments.

The objectives of this study were to: (1) ascertain the preferred limb for initiating compensatory stepping, (2) investigate the determinants of limb preference for initiating compensatory stepping, and (3) investigate the consequences of initiating compensatory stepping with the paretic limb, among individuals with stroke. From our previous pilot work,[8,9] we hypothesized that, for individuals with poststroke hemiparesis, the nonparetic limb is preferred for initiating compensatory stepping. With regard to our second objective, we anticipated that limb preference for stepping would be related to paretic limb motor impairment. The Chedoke-McMaster Stroke Assessment (CMSA) is frequently used clinically to assess motor impairment; therefore, we hypothesized that reduced frequency of stepping with the paretic limb would be related to lower

List of Abbreviations

CMSA	Chedoke-McMaster Stroke Assessment
ICC	intraclass correlation coefficient

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CMSA scores. Conversely, a reduced ability to bear weight on the paretic limb might discourage initiating stepping with the nonparetic limb; therefore, we hypothesized that increased frequency of initiating stepping with the paretic limb would be related to reduced ability to bear weight on the paretic limb. Regarding our third objective, we hypothesized that increased frequency of initiating compensatory stepping with the paretic limb would be related to an increased rate of failed responses (ie, reliance on the safety harness or physical therapist assistance to prevent a fall), particularly for those with severe lower-limb motor impairment. We also sought to determine whether physically blocking the preferred limb would promote stepping with the nonpreferred limb.

METHODS

Participants

We conducted a retrospective chart review of patients with stroke who were assessed in the Balance Mobility and Falls Clinic at the Toronto Rehabilitation Institute. This clinic provides assessment of quiet standing balance and perturbation-evoked compensatory stepping as part of routine care to individuals with stroke attending inpatient rehabilitation. Assessment of compensatory stepping occurred soon after admission to rehabilitation, or for patients who could not stand independently on admission, as soon as they regained independent stance. We included those patients admitted within a 1-year period who completed assessment of perturbation-evoked compensatory stepping (described below). In order to focus the analysis on individuals with stroke-related unilateral deficits, we excluded those with sensorimotor impairment of both lower limbs or those with lower-limb joint replacement. Within the time period, 97 patients completed assessment of perturbation-evoked stepping reactions; 18 were excluded due to bilateral sensorimotor impairment, 6 were excluded due to lower-limb joint replacement, and 24 were excluded because they did not complete enough trials. Forty-nine individuals met the criteria for inclusion in the review. All assessments were performed by a trained physical therapist. Patients' age, sex, stroke location, side of paresis, premorbid limb dominance, and CMSA[10] leg and foot and National Institutes of Health Stroke Scale[11] scores were extracted from clinical charts. Premorbid limb dominance was assessed by asking patients which hand they wrote with and which foot they would have used to kick a ball prior to their stroke. The CMSA assigns a score between 1 and 7 according to the level of motor recovery in the foot and leg and is frequently used to evaluate motor recovery poststroke in clinical settings. Higher CMSA scores indicate improved motor recovery. The CMSA foot and leg scores have good intrarater (intraclass correlation coefficients [ICCs]=0.94–0.98) and interrater (ICCs=0.85–0.96) reliability.[10]

The retrospective review was approved by the institution's research ethics board; a waiver of patient consent for inclusion in the review was approved.

Assessment of Weight Bearing on the Paretic Limb

Weight bearing on the paretic limb was measured while patients stood with 1 foot on each of 2 forceplates[a] in a standardized position (heel centers 17cm apart, 14° between the long axes of the feet[12]) under 2 conditions: standing quietly with eyes open for 30 seconds and bearing as much weight as possible on the paretic limb for up to 20 seconds. A shorter duration was used for the maximal weight-bearing condition, because it is less well-tolerated than the quiet stance condition. The amount of weight borne on the paretic limb, expressed as a percentage of body weight and averaged over the duration of the trial, was calculated. The quiet stance condition provided an estimate of the patients' natural tendency to bear weight on the paretic limb, whereas the maximal weight-bearing condition revealed the patients' capacity to bear weight on the paretic limb.

Assessment of Compensatory Stepping Reactions

A lean-and-release postural perturbation system was used to evaluate control of compensatory stepping.[7] Patients stood in the standardized foot position[12] with 1 foot on each of the 2 forceplates and leaned forward with approximately 10% of body weight supported by a cable attached to the wall. The standardized foot position ensured that the width of the base of support was similar across subjects and the foot orientation was symmetrical for each subject. In a previous study including healthy young adults, a lean of 11% body weight corresponded to a whole-body lean (ie, ankle angle) of approximately 9° from vertical.[7] At an unexpected time, the cable was released and patients started to fall forward. Perturbations of this type and magnitude consistently evoke compensatory stepping reactions in young healthy individuals.[7] Patients completed 2 conditions: preferred response and encouraged use. In the preferred response trials there were no instructions or constraints placed on reactions. In the encouraged-use trials, the patients' preferred limb for initiating compensatory stepping (ie, the limb used most frequently in the preferred response trials) was physically blocked with the physical therapist's hand or foot approximately 5cm in front of the shin. This distance was chosen to be sufficiently close so that patients could not execute an effective step without colliding with the therapist's limb, but not so close that a collision would occur with small postperturbation limb movements. We included only those individuals who completed at least 5 trials in the preferred response condition. Patients wore a safety harness affixed to an overhead frame to prevent a fall in the event of failure to recover balance. A physical therapist also stood near patients to assist them if they were unable to regain stability alone.

A load cell[b] placed in series with the cable attached to the patient's back measured forces placed on the cable prior to the perturbation. The load cell output was monitored prior to the perturbation to ensure consistency of preperturbation lean. The load cell was also used to detect perturbation onset time (ie, time when force recorded was $<$1Nm). Vertical ground reaction forces recorded by the forceplates were used to determine preperturbation load on the paretic limb; this was defined as the percentage of body weight on the paretic limb averaged over 1 second before the perturbation. Load cell and forceplate data were sampled at 256Hz. The assessment was video recorded. The limb used to initiate compensatory stepping was determined from the videos and forceplates; a step occurred if the vertical force on one forceplate was $<$1% body weight and/or there was noticeable forward movement of the foot on the video. Videos were also reviewed to determine if assistance was required from the safety harness or physical therapist to prevent a fall.

Statistical Analysis

The frequency of step initiation with the paretic and nonparetic limb was determined for all trials completed by all patients and for each individual patient. A patient was deemed to have a strong preference for stepping with a specific limb if s/he stepped with that limb in all preferred response trials. Three groups of patients were identified: those with a strong preference for initiating stepping with the paretic limb, those