Impaired reactive stepping is a prevalent problem for patients at discharge from inpatient stroke rehabilitation- a retrospective study

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INTRODUCTION

The risk of falls for stroke survivors is high with significant physical and psychosocial consequences that contribute to decreased independence, activity and participation. Incidence of falls is highest soon after discharge from hospital suggesting we are not optimally identifying those at most risk or preparing these individuals during hospitalization for the challenges they will encounter in their everyday living environment.

While challenges in the community may expose fall risk, the key factor that ultimately determines whether an individual will fall is their ability to recover from a loss of balance, specifically using a rapid stepping response. Reactive stepping responses are not only ‘last resorts’ to large magnitude perturbations but even the preferred response to small magnitude perturbations and commonly observed in real-life situations. Numerous age-related changes in reactive stepping responses have been observed. The elderly are more likely to demonstrate a failed capacity to recover from instability than younger adults and more likely to take multiple steps to restore balance, a consequence of ongoing instability after the initial step. Further, such multi-step responses have been found to be predictive of falls in daily life among older adults.

ABSTRACT

Background & Purpose – Individuals with stroke are at increased risk for falls soon after hospital discharge. The ability to react to a balance perturbation, specifically with a rapid step, is critical to maintain balance and prevent falls. The purpose of the study was to: determine the prevalence of impaired reactive stepping responses in an ambulatory group of patients with stroke who were preparing for discharge into the community and the relationship to patient performance on commonly-used clinical measures of balance, mobility and lower limb impairment.

Methods – A retrospective chart review of patients with stroke who, at time of discharge, had completed a perturbation-evoked reactive stepping assessment.

Results – Sixty-seven of 93 (72%) patients had impaired stepping reactions characterized by: the need for assistance, an inability to step with either lower limb, or the need for multiple step responses. There was a statistical difference in clinical scores between those with and without impaired stepping but groups were characterized by considerable variation in clinical profiles. For example, Berg Balance scores ranged from 29 to 55 out of 56 and gait speeds ranged from 0.17-1.43 m/sec for patients who demonstrated a failed step.

Conclusions – Impaired reactive stepping is a prevalent problem for ambulatory patients with stroke preparing for discharge which could possibly increase their risk of falling when faced with the challenges of community ambulation. Specific tests that target the capacity to perform perturbation-evoked stepping reactions may be important to identify those at risk for falls & to direct appropriate intervention strategies.

Key words: falls, balance perturbation, stroke rehabilitation.

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Despite the importance of reactive stepping and the early work by Harburn and colleagues, proposing a clinical method to test, there exists little research in this area with the stroke population. Our previous pilot work, suggests this is an important area of further study: across patient cases, individuals in sub-acute stages of stroke demonstrated impaired anticipatory postural adjustments, delays in timing, an inability or unwillingness to initiate a step with the paretic limb and the use of multi-step responses or the need for assistance to regain stability. Given the clinical attention directed toward balance and mobility retraining and falls prevention within rehabilitation, there is no doubt that greater insight into the magnitude of this clinical problem for patients with stroke is warranted.

Reactive balance control is less frequently assessed in clinical practice than other aspects of balance, possibly influenced by outcome measures that are most commonly-used in clinical settings. A potential limitation of many clinical measures of balance, mobility or limb control is their focus on volitional limb control and self- governed speed of movement that is fundamentally different than the control and speed required for reactive stepping. Therefore, it is also important to establish the association between patient performance on measures of reactive balance control and typical clinical balance, mobility and limb-impairment measures.

Research conducted in the early phases of recovery is important to inform clinicians and guide interventions to potentially achieve important outcomes prior to discharge home. The present study affords a unique opportunity to examine the underlying problems in reactive control in the early stages of stroke recovery with a focus on the point of discharge from inpatient rehabilitation to the community.

This study aimed to: 1) to characterize the prevalence of residual impairment to reactive stepping among patients being discharged from inpatient stroke rehabilitation; and 2) to determine if commonly-used clinical measures of balance (Berg Balance Scale), walking capacity (gait velocity) and lower limb impairment (Chedoke McMaster Stroke Assessment Impairment Inventory) could differentiate between patients with varying abilities of reactive balance control.

METHODS
This study was a retrospective chart review and was approved by the Research Ethics Board of [Institution name removed].

Setting and Participants
The [Clinic name removed] provides assessments of balance and gait using both technological and clinical measures as part of routine care. Information was extracted from the clinic database for patients assessed between October 2009 and September 2011 who had completed a discharge assessment of reactive stepping. From the 127 patients identified, 34 were excluded: 13 patients did not complete both test conditions (outlined below); 15 patients had been participants in another research study that provided enhanced balance retraining; 3 patients received non-standardized instructions that could influence their responses; and technical difficulties prevented observation and coding of video-recorded responses for 3 patients. Therefore, a final sample of 93 patients was included in subsequent analyses.

Protocol for Reactive Stepping Assessment
Reactive stepping was evaluated using a ‘lean-and-release’ balance perturbation method (Figure 1). Patients leaned forward from their ankles so that body weight was supported by a cable. At an unexpected time, the cable was released forcing patients to elicit a stepping reaction to regain stability. Patients wore a safety harness attached to an overhead support and a physiotherapist provided supervision to ensure safety should balance recovery fail. Patients stood in a standardized foot position (heel centres 0.17m apart, 14cm between the long axes of the feet). Perturbations were delivered under three conditions: 5 trials of unconstrained (UNC) conditions, 1 trial of dual-task condition and 5 trials of encouraged-used (ENC) conditions. The secondary task of the dual-task condition is non-standardized; therefore, these data were not included.
in this study. Pre-perturbation cable load was monitored using a load cell [supplier name removed] mounted in series with the cable and was used to determine the magnitude of the perturbation. The load on the cable was expressed as a percentage of body weight averaged over 1s prior to the perturbation; mean cable load across patients was 9.2% body weight (standard deviation = 2.9% body weight). For reference, a lean of 11% body weight corresponds to a whole-body lean angle of approximately 9° from vertical; this perturbation is of sufficient magnitude to consistently elicit a stepping response in healthy young adults with no balance impairment.28 In UNC, patients were instructed to ‘respond however you would naturally to recover your balance’. In ENC, the preferred stepping limb (the limb used most frequently in UNC) was blocked to force stepping with the opposite limb. A physiotherapist placed his/her hand approximately 5cm in front of the patient’s shin. The patient was instructed to ‘respond however you would naturally to recover your balance knowing that this limb is blocked’. All tests were video-recorded and reviewed to code responses.

**Measures**

Features of reactive stepping extracted from the database were: level of independence following the perturbation (i.e. no assistance versus reliance on the harness or physiotherapist to prevent a fall); multi-step responses (≥ 3 steps); limb used for the initial step. We examined only the first trial response of both the UNC and ENC conditions as this test situation is most similar to that adopted in clinical settings and may have better ecological validity, representing the unpracticed response triggered by a fall in everyday life.31,32

The specific clinical measures extracted from the database were: measures of functional balance (Berg Balance Scale-BBS), walking capacity (gait speed), and lower limb impairment (Chedoke McMaster Stroke Assessment Impairment Inventory-CMSA). Preferred gait speed was measured using a pressure-sensitive mat [supplier name removed]. Subjects walk over the 4.6 metre long mat three times wearing regular footwear. If the patient was tested with and without a walking aid, the average gait speed was chosen from the condition that yielded the fastest pace.

Patient characteristics extracted from the database included gender, age, affected hemisphere, time since onset, severity of post-stroke impairments (National Institutes of Health Stroke Scale-NIHSS), functional mobility status (items of the Clinical Outcome Variables Scale) and patient balance self-efficacy (Activities-specific Balance Confidence scale).

**Data Analysis**

All statistical analyses were performed with SAS 9.3 (SAS Institute, Inc). Descriptive statistics were used to characterize the patient sample. Frequency values were used to describe the prevalence of patient trials exhibiting impaired stepping features. Based on their exhibited stepping reactions, patients were categorized into three groups: i) ‘Failed step’ - patients who demonstrated a failed capacity to step either by requiring assistance in UNC or ENC or attempting to step with the blocked limb during ENC; ii) ‘Multi-step’ - patients who did not require assistance but who required multiple steps to regain stability; and iii) ‘Successful step’ - patients who recovered balance in both conditions with two or less steps and without assistance. A one-way analysis of variance was conducted to determine mean differences between groups on clinical measures; Tukey’s test was used for pairwise comparisons. Exact McNemar’s tests were used to detect differences in the frequency of impaired stepping reactions (failed or multi-step responses) between UNC and ENC conditions. Fisher’s Exact tests were used to detect proportional differences in impaired stepping reactions between those who initiated a step with their affected versus unaffected lower limbs. For all statistical analyses, α=0.05.

**RESULTS**

**Participants**

At discharge, patients were at a high functional-mobility level. Mean walking velocity was 0.80m/s (SD 0.35m/s); 86% were able to walk independently, and approximately half of the patient group could walk distances of greater than 500m. (See Table 1 for full clinical profile). As described above the entire group was sub-divided into 3 groups...
based on stepping ability; there were no significant differences in age ($F_{(2,90)}=1.14, p=0.32$), time since onset of stroke ($F_{(2,90)}=0.36, p=0.70$), inpatient rehabilitation length of stay ($F_{(2,90)}=1.72, p=0.19$), stroke recovery i.e. NIHSS ($F_{(2,82)}=2.05, p=0.14$) or pre-perturbation cable load ($F_{(2,90)}=0.15, p=0.86$) between groups.

**Prevalence of Impaired Stepping Responses**

The frequency of patients exhibiting a failed, multi-step or successful stepping reaction across both UNC and ENC is displayed in Table 2. At time of discharge, only 26/93 (28.0%) patients were able to exhibit a successful step in both UNC and ENC (‘Successful step’ group) or conversely 67/93 (72%) patients had residual impaired stepping reactions. When considering patient performance in either UNC or ENC, 39/93 (42%) patients exhibited a failed step (‘Failed step’ group) and 28/93 (30%) patients exhibited a multi-step reaction to regain stability (‘Multi-step’ group). Multi-step reactions were also prevalent in the ‘Failed step’ group; 43% of the failed step trials also featured multi-step reactions.

The frequency of failed steps and multi-step reactions did not differ between UNC and ENC (p>0.99). In UNC, 43/85 (51%) patients initiated a step with their affected lower limb (8 patients with bilateral impairments were not included in this statistic). The frequency of failed or multi-step reactions was not significantly different for patients who initiated a step with their affected versus unaffacted limb (p=0.65 and p=0.27, respectively). In ENC, 20/93 (22%) patients attempted to initiate a step with the blocked limb; 10/20 patients had their unaffacted limb blocked.

**Relationship to Clinical Measures**

There were significant differences in BBS scores ($F_{(2,87)}=7.36, p=0.001$), walking velocity ($F_{(2,89)}=0.62; p=0.002$), and CMSA leg ($F_{(2,77)}=5.07; p = 0.009$) and foot scores ($F_{(2,77)}=7.55; p=0.001$) across patient groups. Pairwise comparisons revealed significant differences in BBS, walking velocity and CMSA scores between those in the ‘Failed step’ and ‘Successful step’ groups (p<0.05).

Significant differences in mean BBS and CMSA scores were evident between those in the ‘Failed step’ and ‘Multi-step’ groups. In spite of these significant statistical differences between groups, there were a wide range of clinical scores across groups of patients with varying levels of ability (Figure 2). For example, patients in the ‘Failed step’ group demonstrated BBS scores ranging from 29 to 55 out of 56, walking velocity values from 0.17 to 1.43m/s and CMSA leg and foot scores from 2-7 and 2-6, respectively.

**DISCUSSION**

To our knowledge, this is the first study to examine the prevalence of impaired reactive stepping in a large cohort of patients with stroke. The results of this study confirm our early pilot work and demonstrate that, despite having attained a high level of functional mobility, the majority of ambulatory patients discharged from inpatient rehabilitation are unable to successfully use reactive stepping to recover balance following an induced forward fall. Indeed, 72% of patients demonstrated the need for assistance, a failed capacity to evoke a step freely with either limb or the need for multi-step reactions to regain stability. Such balance control issues could put these individuals at significant falls risk when faced with the daily challenges of community mobility and is therefore worthy of more focused clinical attention.

In contrast to our earlier studies, this group did not demonstrate a strong preference to use the non-paretic limb for the initial step. These differences could be attributed to a number of factors including the severity of lower-limb impairments, pre-perturbation asymmetry (increased stance-limb loading prior to the onset of perturbation), or premorbid limb dominance.

Patients were profoundly and equally challenged when stepping in both constrained and encouraged-used conditions and when initiating a step with the affected and unaffected limb. This finding may reflect the unique challenges of those with stroke: difficulties in speed and precision of lower limb control may limit the patient’s ability to step with the affected limb whereas challenges in loading the affected limb may limit the patient’s ability to successfully...
execute a step with the unaffected limb. It may also be important to differentiate between the capacity to initiate a step versus the capacity to execute a step of appropriate length, time and precision to successfully regain stability. Future research is warranted in order to better understand the spatiotemporal characteristics and underlying control issues of reactive stepping that may differentially influence the success or failure when stepping with the affected and unaffected limbs.

When patients were placed in conditions that constrained use of their preferred stepping limb, irrespective of whether it was the affected or unaffected limb, 22% of patients initiated a step with their preferred, but blocked, stepping limb. The failure to freely evoke a balance reaction with either limb could put these individuals at obvious falls risk. The current study is limited to anterior perturbations where the selection of either limb is a possible solution to the balance control challenge. However, when faced with unpredictable, multi-directional, balance perturbations of daily life the need to be able to step with either limb is essential. This finding reinforces the need to assess (and train) stepping reactions of both the non-paretic and paretic limbs and supports the use of encouraged-use paradigms of reactive stepping to provide valuable and additional clinical insights to patient performance.

The BBS is the most commonly-used clinical measure in stroke rehabilitation for balance and fall risk. Gait speed is also often used clinically as an overall measure of walking capacity and preparedness for safe community mobility. Arguably, safe community mobility also encompasses the ability to successfully respond to the countless perturbations to balance that occur in daily activities, such as sudden stops, turns, bumps, slips, and trips. It is noteworthy that neither of these measures could clearly discriminate between patients who, despite being poised for discharge to the community, had impaired stepping reactions that could put them at risk in this environment.

Despite significant group mean differences, clinical measures of balance, walking capacity and lower-limb impairment did not differentiate between groups of patients who successfully executed a reactive step and those who required multiple steps to regain balance, who could be at risk for falls. Also, the wide range of clinical scores for those with failed stepping reactions when balance was perturbed suggests that there are challenges in using these measures to predict performance at the level of the individual patient. This may suggest that clinical measures that assess balance and mobility through voluntary movement do not appropriately challenge the individual with the timing or stability requirements necessary for successful perturbation-evoked balance responses; they may provide misleading information about patients’ balance abilities in these situations.

A strength of this study is its ability to characterize performance in the ‘typical’ patient. This was made possible by the implementation of a lean-and-release methodology in routine clinical practice, a safe, standardized protocol to measure capacity for reactive stepping within the sub-acute stages of stroke. The present study was limited to observational analysis; future studies using kinetic, kinematic and electromyography analysis are warranted to better characterize and understand the underlying control issues of reactive stepping after stroke. The lean-and-release methodology is intended to evoke compensatory balance reactions in response to temporally unpredictable perturbations. The methodology is obviously not intended to mimic ‘real-world’ falls that may occur under various environmental conditions but rather to reveal the capacity to respond to challenging perturbations to balance. Studies to determine the relationship of reactive stepping measures using this methodology to fall risk after stroke are currently underway by our research team.

**CONCLUSIONS**

Impaired balance-recovery stepping reactions are a prevalent problem among ambulatory stroke patients preparing for discharge, which could increase risk of falls when faced with the challenges in the community.
This aspect of balance assessment is therefore worthy of more focused clinical attention. Specific tests that target the capacity to perform reactive stepping may be important to identify those at risk for falls and to direct appropriate intervention strategies.

Table 1. Clinical profile of patients by category of reactive stepping ability.

<table>
<thead>
<tr>
<th>Variable</th>
<th>All n=93</th>
<th>Failed step n=39</th>
<th>Multi-step n=28</th>
<th>Successful step n=26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>66.1 (13.9)</td>
<td>67.5 (14.3)</td>
<td>67.5 (13.1)</td>
<td>62.7 (13.9)</td>
</tr>
<tr>
<td>Gender (male:female)</td>
<td>62:31</td>
<td>16:23</td>
<td>8:20</td>
<td>7:19</td>
</tr>
<tr>
<td>Inpatient rehab LOS (days)</td>
<td>34.6 (12.4)</td>
<td>37.4 (13.2)</td>
<td>32.6 (11.5)</td>
<td>32.5 (11.6)</td>
</tr>
<tr>
<td>Time post-stroke (days)</td>
<td>48.5 (19.7)</td>
<td>48.4 (15.7)</td>
<td>50.8 (25.8)</td>
<td>46.2 (18.1)</td>
</tr>
<tr>
<td>NIHSS</td>
<td>4.4 (3.1)</td>
<td>5.2 (3.7)</td>
<td>3.9 (2.4)</td>
<td>3.8 (2.5)</td>
</tr>
</tbody>
</table>

*Functional Mobility Independence*

<table>
<thead>
<tr>
<th>Out: In: Sup'd</th>
<th>None: SPC: QC/W</th>
<th>&gt;500m:&lt;500m:&lt;100m</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=88</td>
<td>n=88</td>
<td>n=87</td>
</tr>
<tr>
<td>7:20:10</td>
<td>11:7:19</td>
<td>15:16:6</td>
</tr>
<tr>
<td>10:17:0</td>
<td>15:6:6</td>
<td>11:11:2</td>
</tr>
<tr>
<td>13:5:6</td>
<td>18:8:0</td>
<td>9:15:0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BBS (out of 56)</th>
<th>47.5 (7.7)</th>
<th>44.2 (8.0)</th>
<th>50.5 (4.4)</th>
<th>49.5 (8.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking velocity (m/sec)</td>
<td>0.80 (0.35)</td>
<td>0.67 (0.33)</td>
<td>0.81 (0.28)</td>
<td>0.98 (0.37)</td>
</tr>
</tbody>
</table>

| CMSA (out of 7) Leg |                  |                  |                  |                  |
| Foot              | 5.1 (1.6) | 4.7 (1.2) | 5.3 (0.8) | 5.4 (0.9) |
|                  | (n=80)    | (n=11)      | (n=80)        | (n=86)        |
|                  | 4.5 (1.1) | 4.0 (1.2) | 4.8 (1.0) | 5.0 (0.8) |

<table>
<thead>
<tr>
<th>ABC (out of 100)</th>
<th>70.4 (7.7)</th>
<th>68.9 (17.5)</th>
<th>69.5 (15.6)</th>
<th>73.6 (22.9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable Load (%total body weight)</td>
<td>9.2 (2.9)</td>
<td>9.4 (3.3)</td>
<td>9.0 (2.3)</td>
<td>9.1 (2.9)</td>
</tr>
</tbody>
</table>

n=93 unless otherwise specified. Values represent means (SD) or counts. LOS= length of stay, NIHSS=National Institutes of Health Stroke Scale. BBS=Berg Balance Scale. Out:In:Sup’d=walking independently outdoors, indoors only or requires supervision, respectively. SPC=single point cane. QC/W=quad cane/ walker. CMSA=Chedoke McMaster Stroke Assessment Impairment Inventory. ABC=Activities-specific Balance Confidence Scale.
Table 2. Frequency of patients (n=93) who exhibited impaired reactive stepping features across unconstrained (UNC) and encouraged-use (ENC) conditions.

<table>
<thead>
<tr>
<th>Unconstrained Response (UNC)</th>
<th>Encouraged-Use Response (ENC)</th>
<th></th>
<th></th>
<th></th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failed step</td>
<td>Multi-step</td>
<td>Successful step</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Assist or Step with Blocked</td>
<td>(No assist, ≥ 3 steps)</td>
<td>(No assist, ≤ 2 steps)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failed Step</td>
<td>16 (17.2)</td>
<td>5 (5.4)</td>
<td>6 (6.5)</td>
<td>27 (29.0)</td>
<td></td>
</tr>
<tr>
<td>(Assist)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-step</td>
<td>5 (5.9)</td>
<td>13 (14.0)</td>
<td>8 (8.6)</td>
<td>26 (28.0)</td>
<td></td>
</tr>
<tr>
<td>(No assist, ≥ 3 steps)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Successful step</td>
<td>7 (7.5)</td>
<td>7 (7.5)</td>
<td>26 (28.0)</td>
<td>40 (43.0)</td>
<td></td>
</tr>
<tr>
<td>(No assist, ≤ 2 steps)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>28 (30.1)</td>
<td>25 (26.9)</td>
<td>40 (43.0)</td>
<td>93 (100)</td>
<td></td>
</tr>
</tbody>
</table>

Values represent number (%) of patients. Bold outlines demarcate patients who demonstrated a failed step or multi-step in either UNC or ENC conditions and patients who demonstrated a successful step in both conditions; these patients represent those categorized in the ‘Failed step’ (n=39), ‘Multi-step’ (n=28) and ‘Successful step’ (n=26) patient groups.

Figure 1. The ‘lean and release’ balance perturbation method. The patients wear a safety harness that is attached to an overhead support structure and lean forward on cable connected to the wall. The cable is released unexpectedly inducing a forward fall.
Figure 2. Scatterplot of individual patient Berg Balance scores (A) and walking velocity values (B) by sub-group of reactive stepping ability. Asterisks represent significant group mean differences.
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17. [Author information removed]

18. [Author information removed]


37. [Author information removed]


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CONFLICTS OF INTEREST:

None identified

DISCLOSURES:

None declared.