A Clinical Measurement of Maximal and Rapid Stepping in Older Women

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Background. In older adults, clinical measures have been used to assess fall risk based on the ability to maintain stance or to complete a functional task. However, in an impending fall situation, a stepping response is often used when strategies to maintain stance are inadequate. We examined how maximal and rapid stepping performance might differ among healthy young, healthy older, and balance-impaired older adults, and how this stepping performance related to other measures of balance and fall risk.

Methods. Young (Y; n = 12; mean age, 21 years), unimpaired older (UO; n = 12; mean age, 69 years), and balance-impaired older women (IO; n = 10; mean age, 77 years) were tested in their ability to take a maximal step (Maximum Step Length or MSL) and in their ability to take rapid steps in three directions (front, side, and back), termed the Rapid Step Test (RST). Time to complete the RST and stepping errors occurring during the RST were noted.

Results. The IO group, compared with the Y and UO groups, demonstrated significantly poorer balance and higher fall risk, based on performance on tasks such as unipedal stance. Mean MSL was significantly higher (by 16%) in the Y than in the UO group and in the UO (by 30%) than in the IO group. Mean RST time was significantly faster in the Y group versus the UO group (by 24%) and in the UO group versus the IO group (by 15%). Mean RST errors tended to be higher in the UO than in the Y group, but were significantly higher only in the UO versus the IO group. Both MSL and RST time correlated strongly (0.5 to 0.8) with other measures of balance and fall risk including unipedal stance, tandem walk, leg strength, and the Activities-Specific Balance Confidence (ABC) scale.

Conclusions. We found substantial declines in the ability of both unimpaired and balance-impaired older adults to step maximally and to step rapidly. Stepping performance is closely related to other measures of balance and fall risk and might be considered in future studies as a predictor of falls and fall-related injuries.

Falls are a significant health threat to older adults. A number of clinical measures have been proposed to assess standing balance and fall risk. These generally assess corrective balance responses (1). Corrective responses do not result in a change in the base of support configuration. Typical corrective responses involve leg muscle activation patterns, such as the "ankle" or "hip" strategy and cocontraction, as well as associated arm movements (2). Assessments of corrective responses involve either the ability to stay within one's base of support with minimal movement or the ability to move maximally without taking a step. These assessments include bipedal (3) and unipedal stance (4), a battery of bipedal, unipedal, and tandem stances (5), functional reach (6), and dynamic posturography (7). In addition to these postural tasks, a number of test batteries to assess standing balance and fall risk during functional task performance have been devised, such as the Timed Up and Go (8), Berg Functional Balance Scale (9), and the Performance-Oriented Mobility Assessment (10). Although these measures assess corrective responses to a balance perturbation and functional daily activities, they generally do not assess protective strategies (1) that may be utilized when a corrective response is inadequate, for example, stepping to avoid an impending fall.

Protective strategies involve alterations in the base of support. These strategies may be used either to prevent a fall or lessen the effects of a fall and typically include rapid protective stepping (11,12). In response to a postural perturbation, an individual will step when a corrective response is insufficient (13). Older adult fallers use stepping responses more frequently than nonfallers, particularly at lower levels of postural disturbance (14,15). Although stepping responses have been studied experimentally, no clinical measure of maximal or rapid stepping exists. This study examines a potentially clinically applicable maximal and rapid stepping measure and compares this measure with existing balance and fall risk assessments.

The purpose of this study is to assess the ability of healthy young, healthy older, and balance-impaired older women to step maximally (Maximum Step Length or MSL) and rapidly in multiple directions (termed the Rapid Step Test or RST) and relate this stepping performance with clinical balance and fall risk assessments. We hypothesized that the healthy young, compared with the healthy older women, and the healthy older, compared with the balance-impaired older women, would step further (higher MSL), more quickly (faster RST), and with fewer RST errors. We also hypothesized that the MSL and RST would correlate well with existing clinical balance and fall risk assessment measures.

Methods

Subjects

Volunteers were recruited from among university students (young, Y) and from a database of older adults willing
to participate in university-based experiments. Subjects underwent a medical history and physical examination by a nurse clinician, directed toward the musculoskeletal and neurological systems. Subjects were excluded if they were medically unstable (i.e., having ongoing chest pain or marked dyspnea, an acute infection or inflammation [such as joint pain flare], or severe spinal or lower extremity joint pain). Subjects had to have adequate standing balance (i.e., the ability to stand bipedally with eyes open for 30 seconds). Subjects were also excluded if they demonstrated substantial dementia (Mini-Mental State Examination <23 of 30) (16) and depression (short-form Geriatric Depression Scale score >5 out of 15) (17). Volunteers were considered balance-impaired older (impaired older, IO) if they had sustained more than one fall in the past year and had a subjective complaint of frequent unsteadiness. Healthy older volunteers (unimpaired older, UO) admitted to one fall or less in the past year, denied any significant musculoskeletal, neurological, or otological impairment, and had no significant abnormal findings on physical examination.

Rapid Step Test

Subjects were given a 10-minute cardiovascular and musculoskeletal warm-up prior to onset of testing.

MSL determination.— Each subject was tested for MSL in the front, side, and back directions in each lower extremity. The subjects—with their arms crossed over their chests—were told to step maximally with one leg while keeping the other leg planted and then return to the initial position in one step for each leg (left, right) and direction (front, side, back). Following three trials of submaximal stepping (in each leg direction), MSL was defined for each leg direction as the average step length over a series of five trials.

RST determination.— Subjects were instructed to step as fast as possible with one leg in a given direction as commanded by the tester and return to the initial starting position. Subjects then continued with rapid stepping in response to the tester’s next leg-direction command. Subjects were required to step at least 80% of their MSL for all directions as marked with a taped line on the floor. Following a set of practice steps (four steps in each leg direction, e.g., left front), both legs were tested in a series of randomly ordered directions, four steps in each leg direction, for a total of 24 repetitions. An error was defined as (i) loss of balance, (ii) failure to return to initial position, (iii) multiple steps, and (iv) noncompliance with direction or side. The testing order was repeated with different random-order sequences for a total of three sets of 24 repetitions. Total timing and error data were recorded for each repetition set. Data from the first set were used for the primary RST analysis, which is discussed later, and data from the second and third sets were used to ascertain RST interset reliability.

Reliability.— Same-day test-retest reliability was examined among values of the three RST sets for timing and errors. Within-week reliability for both MSL and for the three RST sets was also analyzed between the primary session and a second session conducted within the same week. Within-week interrater reliability for the total number of errors was also ascertained for the first RST set.

Clinical Balance and Fall Risk Assessment

A series of measures that related to balance and fall risk were assessed. All timing was performed using a hand-held stopwatch.

Maintenance of stance and dynamic balance.—Two maintenance of stance and one dynamic balance task were assessed. Following three practice trials, tandem and unipedal stance (stake maintenance tasks) were tested for three trials each for a duration up to 60 seconds. For tandem stance, subjects stood heel to toe, using their preferred foot position for front and back foot. For unipedal stance, subjects stood with their lifted foot approximately 2 inches from the medial malleolus of the stance foot without making lifted foot-malleolus contact. Subjects stood first on their preferred leg, followed by the opposite leg, and then their preferred leg again, while keeping their arms across their chest. The average time of three trials for maintenance of position of each task was recorded. Tandem walk (dynamic balance task) was then tested for three trials each. Subjects were required to walk heel to toe along a 10-foot line. They were asked to walk as quickly as they could without misstepping. A misstep occurred when subjects stepped completely off the line or failed to follow a heel-to-toe pattern. The number of missteps and walk time were then averaged over the three trials.

Leg strength.— Using an isokinetic dynamometer (Biodex Multisystem 2AP, Biodex Medical, Shirley, NJ) with standard positioning and strap restraints, peak maximum isokinetic torque was tested at slow and fast speeds for knee extension (120 and 300°/s) and ankle plantarflexion (60 and 120°/s). Peak torque over five repetitions was recorded for each joint movement direction in the dominant (right) leg.

Self-reported efficacy in maintaining balance.— Degree of perceived efficacy in maintaining balance or becoming unsteady while performing common community-dwelling activities was measured using the Activities-Specific Balance Confidence (ABC) scale (18).

Data analysis.— All group comparisons were evaluated using analysis of variance (ANOVA) and Fisher’s protected least significant difference for pairwise comparisons. All correlations and reliability were assessed using the Pearson correlation coefficient. ANOVA for torque comparisons utilized two independent variables: group and speed.

Results

Subjects

Thirty-four women (12 Y, 12 UO, 10 IO) completed the testing. Mean (±SD) age of the Y group was 21 years (±2 years), and the UO group (69 ± 3 years) were younger than the IO group (77 ± 6 years; p < .0001). Mean (±SD) body mass index (in kg/m²) was significantly lower in the Y group (21 ± 2 kg/m²; p < .005) than in the UO (27 ± 6 kg/m²) or the IO groups (27 ± 4 kg/m²).
Mean (±SD) MSL (in inches) is presented for front, side, and back steps in the right leg (see Figure 1). Mean MSL ranged from 43–44 inches for Y, 36–37 inches for UO, and 25–26 inches for the IO group, with essentially no difference between front, side, and back steps, and (not pictured) no left to right side differences. MSL was significantly greater in the Y versus UO group (by 16%) and in the UO versus IO group (by 30%, p < .0001).

**RST**

Mean RST time and errors are presented in Figures 2 and 3, respectively. Mean RST time was significantly faster in the Y versus UO group (by 24%) and in the UO versus IO group (by 15%, p < .01). Mean RST errors tended to be higher in the UO than in the Y group, but were statistically significantly higher only in the UO versus the IO group (p < .001). Faster RST time (shorter time) correlated significantly with longer MSL in all three directions (r ranging from −0.69 to −0.74).

**RST and MSL Test-Retest Reliability**

Reliability was generally good. Same-day and within-week reliability for RST ranged from 0.71–0.97 and 0.80–0.91, respectively. Within-week MSL reliability ranged from 0.87–0.90. Inter-rater reliability for the number of RST errors was also high, 0.98 for the primary session and 0.95 for the follow-up session.

**Clinical Balance and Fall Risk Measures**

As shown in Table 1, clinical balance and fall risk measures differed generally between the three experimental groups. Those in the Y group stood significantly longer in unipedal stance than did the UO group, and the UO group stood longer than did those in the IO group (p < .0001). Although tandem stance time and tandem walk time and errors did not differ significantly between the Y and UO groups, compared with the UO group, the IO group had significantly shorter tandem stance, slower tandem walk time, and higher tandem walk errors (each p < .0001). All of these results indicate poorer standing and dynamic balance and potentially higher fall risk in the IO compared with UO group. Similarly, the ABC score did not differ between Y and UO groups, but was lower in the IO compared with the UO group, suggesting a group that was less confident in their balance ability. Results of the mean peak torque output showed a significant group difference effect (Y greater than UO, and UO greater than IO) for both knee extension and ankle plantarflexion (for each joint, each pairwise comparison p value < .01). Mean peak torque was higher for the lower speeds at each joint: 120° greater than 300° (p < .0001) for knee extension, and 60° greater than 120° (p < .004) for ankle plantarflexion.

**Relationship Between Clinical Balance and Fall Risk Measures and Stepping Performance**

A number of the balance and fall risk measures were highly correlated with MSL and RST time (see Table 2).
Because MSL was similar in each leg direction, only the right leg-front direction data were used for these correlations. Highest correlations were found between unipedal stance and MSL (0.84, \( p < .0001 \)) and between unipedal stance and RST time (–0.81, \( p < .0001 \)). Other measures of balance and fall risk were highly correlated with MSL (range 0.60–0.76, \( p < .0001 \)) and with RST time (–0.54 to –0.61, \( p < .002 \)).

**DISCUSSION**

As a potential clinical measure of fall risk, a measure of protective balance response, rather than corrective balance response (i.e., stepping performance), was studied. These stepping measures, specifically MSL, RST time, and RST errors, appear to be valid measures of underlying balance impairment. Stepping performance was decreased in unimpaired (healthy) older, compared with healthy young women, and in balance-impaired older, compared with the unimpaired older women. There was a strong relationship between stepping performance and other balance and fall risk assessment measures. Specifically, there was a strong correlation between MSL and RST and (i) clinical measures for corrective balance, dynamic balance, and self-report balance confidence, and (ii) lower extremity strength output. Finally, these stepping performance outcomes were highly reproducible.

The group differences noted are as strong in MSL and RST error as in the RST time. The correlations between the balance and fall risk measures are as strong or stronger with MSL as with RST time. Eventually, MSL and RST error may prove to be as powerful predictors of balance impairment and fall risk as the RST time itself. Administration of the RST will readily generate MSL and RST error anyway, partly because the RST requires MSL assessment, and because RST errors are easily identified.

A strong relationship was found between unipedal stance time and MSL (\( r = .84 \)) and RST time (–0.81), possibly suggesting that a simple unipedal stance time assessment is sufficient to assess fall risk. However, when reanalyzing the MSL and RST time-unipedal stance time correlation according to group, the subject group most at risk for falls, the IO and not the UO group, had a nonsignificant \( r \) result. This may be due to the globally poor IO group’s unipedal stance performance. This may also suggest that the MSL and RST time tap a unique dimension of balance response in these at-risk individuals, perhaps the protective, rather than the corrective aspect.

The stepping performance required in the present study is biomechanically complex. One major issue is how the biomechanics of an involuntary step response, thought to be the usual response to an impending fall, may differ between healthy young and healthy older women in the kinematics of these rapid steps, either voluntary or involuntary (19,20). What may differ between the old and young, in both voluntary and involuntary stepping, is the older adults utilize a longer period of time prior to lift-off for response planning, for reaction time, and for preliminary postural adjustments (such as additional weight shifting) (12,20–23). Thus, the MSL and RST group differences in the present study may reflect aspects of initiation and preparation for stepping, rather than only the step taking itself.

The experimental protocol used (front, side, back) is similar to that used by Patla (23), who found age-related differences in step initiation. The Patla protocol involved only one leg, and there was no attempt to specify a certain step length (\( \geq 80\% \) of MSL in the present study). The use of the 80% MSL criteria for the RST seems justified given that first-step responses to a slip or trip may require as much as a full step length (12). Future studies may consider RST protocol alterations, such as reducing the percentage of MSL required, to determine the influence of percentage of MSL on the RST outcomes. The RST also requires the subject to return to the original position from the \( \geq 80\% \) MSL; the return is a separate balance task that has not been well studied. It may be that the RST group differences occur more in the time taken to return to bipedal stance rather than in the time taken to initiate and complete the step. Further biomechanical studies fractionating the step initiation, step completion, and return to bipedal stance would thus be useful.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Y (n = 12)</th>
<th>UO (n = 12)</th>
<th>IO (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unipedal stance (s)</td>
<td>60.0 ± 0.0</td>
<td>30.2 ± 21.8</td>
<td>3.8 ± 3.6</td>
</tr>
<tr>
<td>Tandem stance (s)</td>
<td>60.0 ± 0.0</td>
<td>57.3 ± 5.3</td>
<td>17.9 ± 23.6</td>
</tr>
<tr>
<td>Tandem walk (s)</td>
<td>7.5 ± 1.1</td>
<td>8.5 ± 1.6</td>
<td>17.0 ± 3.5</td>
</tr>
<tr>
<td>Tandem walk errors</td>
<td>0.0 ± 0.0</td>
<td>0.5 ± 0.5</td>
<td>4.4 ± 3.2</td>
</tr>
<tr>
<td>ABC (total score)</td>
<td>96.9 ± 1.0</td>
<td>95.2 ± 6.3</td>
<td>68.6 ± 16.0</td>
</tr>
<tr>
<td>Knee extension 120°/s (N-m)</td>
<td>68.2 ± 17.0</td>
<td>46.9 ± 14.7</td>
<td>34.0 ± 10.8</td>
</tr>
<tr>
<td>Knee extension 300°/s (N-m)</td>
<td>38.1 ± 12.2</td>
<td>30.1 ± 11.2</td>
<td>20.3 ± 8.2</td>
</tr>
<tr>
<td>Ankle plantarflexion 60°/s (N-m)</td>
<td>40.6 ± 16.4</td>
<td>29.9 ± 13.1</td>
<td>17.6 ± 7.6</td>
</tr>
<tr>
<td>Ankle plantarflexion 120°/s (N-m)</td>
<td>28.9 ± 12.5</td>
<td>20.9 ± 10.5</td>
<td>12.5 ± 5.2</td>
</tr>
</tbody>
</table>

**Table 1. Mean (± SD) Clinical Balance and Fall Risk Assessment Measures in Young (Y), Unimpaired Older (UO), and Impaired Older (IO)**

<table>
<thead>
<tr>
<th>Measure</th>
<th>MSL</th>
<th>RST Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unipedal stance time</td>
<td>0.84</td>
<td>–0.81</td>
</tr>
<tr>
<td>Tandem stance time</td>
<td>0.74</td>
<td>–0.60</td>
</tr>
<tr>
<td>Tandem walk time</td>
<td>0.76</td>
<td>0.61</td>
</tr>
<tr>
<td>Tandem walk errors</td>
<td>0.68</td>
<td>0.51</td>
</tr>
<tr>
<td>Knee extension 120°/s</td>
<td>0.69</td>
<td>–0.70</td>
</tr>
<tr>
<td>Knee extension 300°/s</td>
<td>0.60</td>
<td>–0.70</td>
</tr>
<tr>
<td>Ankle plantarflexion 60°/s</td>
<td>0.65</td>
<td>–0.61</td>
</tr>
<tr>
<td>Ankle plantarflexion 120°/s</td>
<td>0.65</td>
<td>–0.60</td>
</tr>
<tr>
<td>ABC questionnaire</td>
<td>0.75</td>
<td>–0.54</td>
</tr>
</tbody>
</table>

**Table 2. Correlations Between Maximum Step Length (MSL), Rapid Step Test (RST) Time, and Balance and Fall Risk Measures**

Notes: ABC = Activities-specific Balance Confidence scale; N-m = Newton-meters.
Other sources of RST variability may occur in the method of presenting the stimulus to initiate the step. Some studies use a light cue (23,24), and others have used a gentle waist pull (19) to get the subject to initiate a voluntary step. The method chosen here—a verbal command—seemed more clinically applicable than using a complicated light array (requiring three directions for each leg) or the apparatus necessary to generate a waist pull (again in three directions for each leg). Although subjects in the present study had no significant hearing or cognitive deficits, the RST may be less useful for patients with substantial hearing impairment who may misinterpret the verbal commands. Volitional stepping in response to any command requiring cognitive processing may be unreliable in patients with cognitive impairment, no matter if light, waist pull, or verbal stimuli are used. Nevertheless, having a cognitive processing component as part of a fall risk measure seems valuable. Postural responses are clearly influenced by a number of behavioral factors (2), including cognition and affect. Other behavioral measures, such as confidence in balance ability, also predict performance, as evidenced by the strong relationship between MSL and RST time and the ABC scale in the present study.

Strength is likely an important contributor to rapid stepping. The ability to produce torque rapidly (i.e., rate of torque development) at the ankle decreases with age (25). In the present study, MSL and RST time correlated strongly with peak knee extension and ankle plantarflexion torque. Although peak torque decreased at the higher speeds, there was no major difference in MSL or RST peak torque correlations (according to speed), and no group-speed interactions to suggest a disproportionate loss of strength at the higher speeds in the impaired older women. Whether changes in rate of torque development underlie changes in rapid stepping ability is the subject of an ongoing intervention study.

This study demonstrated a strong relationship between clinical balance measures and stepping performance. Established balance measures, such as functional reach and unipedal stance, are typically corrective responses, but rapid stepping is a protective response. Whether stepping performance is ultimately a better predictor of falls or fall injuries than these other measures is not known; this is the goal of an ongoing intervention study. Alternatively, corrective and protective response measures may complement each other in assessing balance maintenance and fall risk. Stepping measures may ultimately be more appropriately applied in older adults who are exposed to trips and slips, particularly as a result of environmental hazards. In these fall risk situations, rapid stepping becomes increasingly important to avoid falls.

Acknowledgments

The authors gratefully acknowledge the support of the National Institute on Aging (Grants AG08808 [Michigan Older Americans Independence Center] and AG10542), as well as the Office of Research and Development, Medical Service and Rehabilitation Research and the Development Service of the Department of Veterans Affairs. The authors also acknowledge the assistance of Chris Eubank, Elizabeth Peterson, and Julie Grunawalt in subject recruitment and assessment and in data acquisition.

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References


21. Patla AE, Frank JS, Winter DA, et al. Age-related changes in balance measures, such as functional reach and unipedal stance, are typically corrective responses, but rapid stepping is a protective response. Whether stepping performance is ultimately a better predictor of falls or fall injuries than these other measures is not known; this is the goal of an ongoing intervention study. Alternatively, corrective and protective response measures may complement each other in assessing balance maintenance and fall risk. Stepping measures may ultimately be more appropriately applied in older adults who are exposed to trips and slips, particularly as a result of environmental hazards. In these fall risk situations, rapid stepping becomes increasingly important to avoid falls.

A complete list of references is available from the author.

Received June 13, 2000
Accepted February 15, 2000

Decision Editor: John Morley, MB, BCH