Comparison of Older Adult Performance During the Functional-Reach and Limits-of-Stability Tests

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Despite widespread use of the functional-reach (FR) and limits-of-stability (LOS) tests, comparisons of postural strategies and postural limits for these tests have not been previously reported. The purpose of this study was to compare postural strategies as determined by cross-correlation analyses of trunk and lower leg angular displacements and postural limits as assessed by maximum center-of-gravity (COG) excursions as older adults at low fall risk completed the FR and LOS tests. Fourteen older adults completed three FR and LOS trials while standing on a Balance Master® force platform. Results indicated that despite relatively similar instructions to reach or lean as far as possible without losing balance or altering the base of support, their performance differed with regard to postural strategies employed and maximum COG excursions produced. These findings suggest that because of differences in task constraints, FR and LOS tests should not be used interchangeably.

Key Words: postural strategy, postural limits, balance

Maintaining balance when reaching or leaning through the region of stability requires adopting a movement strategy that allows for effective control of the center of gravity (COG) with respect to the base of support. For many older adults, declines in spatial and temporal control of the COG, reduced postural limits, or a limited repertoire of movement strategies results in an increased risk of falls when performing reaching or leaning activities. Consequently, balance assessments and fall-risk screenings with older adult populations often include the functional-reach (FR) or limits of stability (LOS) test (Horak, 1997; Woollacott & Shumway-Cook, 1997).

The FR test developed by Duncan and colleagues offers therapists an inexpensive and simple clinical measure of an individual’s ability to reach forward while maintaining a fixed base of support (Duncan, Weiner, Chandler, & Studenski, 1990). Although this test simply measures reaching distance achieved during forward leaning, these investigators contend that maximum forward reach assessed using the FR test yields reliable scores that provide a clinical approximation of the postural limits measured with force-plate systems during similar tasks. Furthermore, the
predictive validity of the test in terms of fall risk is well-established (Duncan et al., 1990; Duncan, Studenski, Chandler, & Prescott, 1992).

The LOS test available on various NeuroCom® balance systems affords clinicians a more sophisticated assessment of postural limits by assessing the degree to which an individual is able to lean in several directions while maintaining balance with a fixed base of support. The LOS performance variable, maximum excursion, is based on COG movement and is expressed as a percentage of a theoretical limit of stability (Nashner & McCollum, 1985; NeuroCom International, 2001; Schieppati, Hugon, Grasso, Nardone, & Galante, 1994). As with the FR test, the LOS test has been shown to provide reliable scores that are predictive of fall risk (Clark, Rose, & Fujimoto, 1997; Girardi, Konrad, Amin, & Hughes, 2001; Trueblood, Hodson-Chennault, McCubbin, & Youngclarke, 2001; Wallmann, 2001).

Although both of these tests involve forward leaning, the nature of the tasks being performed might in fact be quite different. For example, the task goals of the two tests, although similar, are not identical. In the FR test, the goal is to reach as far as possible with a closed fist while leaning forward. In the LOS test, sensors in a force plate on which the individual is standing transmit the position of the COG to a computer monitor in the form of a visual cursor that the individual views while leaning. The goal on the 100% LOS test is to position this visual cursor within an on-screen target representing the individual’s maximum leaning limit. Given these subtle differences in the LOS and FR task goals, these tests might in fact not be measuring postural limits in as similar a fashion as has been contended previously by other investigators (Duncan et al., 1990). Indeed, a recent study reported by Wallmann (2001) indicated that FR scores correlated poorly with measures of COG displacement during LOS performance for both elderly fallers ($r = –.009$) and nonfallers ($r = .17$).

In addition to assessing postural limits, several researchers and clinicians have suggested that postural strategies be evaluated when conducting tests of reaching or leaning performance (Horak, Shupert, & Mirka, 1989; Newton, 1997; Rose, 2002; Woollacott & Shumway-Cook, 1996). The manner in which an individual coordinates and controls body segments to produce changes in COG position might reveal compensatory movement strategies associated with task constraints or underlying impairments or pathologies. Recent investigations indicate that healthy older adults and individuals with vestibular dysfunction generally adopt postural strategies that involve hip flexion and ankle plantar flexion (i.e., hip strategy) during FR performance (Jonsson, Henriksson, & Hirschfeld, 2003; Wernick-Robinson, Krebs, & Giorgetti, 1999). When contrasting maximum anterior COG displacement during the FR for individuals using a hip strategy with those using other or nonhip strategies (e.g., ankle, suspensory, trunk rotation), Wernick-Robinson and colleagues found that despite no statistical differences in the mean COG displacements between healthy older adults and individuals with vestibular dysfunction, COG displacement had a strong, positive correlation with these other or nonhip strategies. Although Wallmann (2001) did not assess postural strategies when comparing the FR and LOS performance of older adult fallers and nonfallers, he suggested that possible
differences in strategies might explain the poor correlations between FR distance and anterior displacement on the LOS.

Although both the FR and LOS tests might assess fall risk to an acceptable degree, it is plausible that the goals or constraints for the two tests are perceived differently during task performance. As such, not only might the employed movement strategies for the tests be different but so too might the degree of anterior COG displacement. These differences would help explain the reported low correlation between scores on these two purported tests of postural limits. To date, no previously reported investigation has intentionally compared postural strategies for the FR and LOS tests. In addition, no investigation has compared the maximum anterior COG excursion scores obtained on the FR test with those obtained on the LOS test. Therefore, the purpose of this study was to compare the postural strategies of older adults at low risk for falls during performance of the FR and LOS tests, as well as to examine the maximum anterior COG excursions occurring during each test.

Methods

PARTICIPANTS
Fourteen older adults, 5 men and 9 women ranging in age from 71 to 81 years ($M = 76.5$), were recruited from a local continuing-care community to participate in the study. A prestudy screening was conducted using functional and clinical tests of balance and mobility that are reported to have good sensitivity or predictability for falls or fall risk among older adults (Bennett & Karnes, 1998; Shumway-Cook & Woollacott, 2001). Of 55 older adults who completed the screening, the 14 study participants met specific criteria for low fall risk, including (a) no self-reported history of falls or poor self-perceptions of balance (balance efficacy scale $>70$; Rose, 2003), (b) no problems with dizziness or unsteadiness, (c) Berg balance-scale scores greater than 50/56 (Berg, Wood-Dauphinée, Williams, & Gayton, 1989; Riddle & Stratford, 1999; Shumway-Cook, Baldwin, Pollisar, & Gruber, 1997), (d) timed up-and-go completed in less than 10 s (Podsiadlo & Richardson, 1991; Shumway-Cook, Brauer, & Woollacott, 2000), and (e) no falls on the modified clinical test of sensory interaction on balance (Shumway-Cook & Horak, 1986). Persons with diseases known to adversely affect balance and mobility (e.g., Parkinson’s disease, diabetes), permanent orthopedic impairments, or visual deficits not correctable with lenses were excluded from participation. All participants provided informed consent in accordance with policies outlined by the institution’s institutional review board.

EQUIPMENT
All testing was conducted using the Balance Master® system (software version 6.11) with a long force platform. The force-plate system comprises four force transducers that quantify changes in the vertical pressures applied to the support
surface. Vertical pressure data are used to derive anteroposterior and mediolateral coordinates of the center of pressure (COP). The Balance Master software uses the instantaneous COP position and estimates of the body’s center of mass (which is based on the participant’s height) to calculate a projected COG position.

Kinematic data for determining postural strategies were obtained using a Skill Technologies 6-D research system. This system consists of motion-capture and -analysis software and an electromagnetic tracking device. Using a transmitter that generates a low-frequency electromagnetic field and sensors that detect this field, the three-dimensional coordinate positions and orientation angles (i.e., pitch-yaw-roll) of each sensor’s motion were determined during task performance. Segmental linear and angular displacements were derived from these data.

PROCEDURES

Before testing began, motion sensors were secured to the participant’s trunk (at T1–T2), right lower leg (immediately distal to the tibial tuberosity), and right hand (at the third metacarpal) using Velcro straps. The participant was assisted onto the force platform and asked to stand quietly and still in the anatomical position with his or her feet in a standardized foot location. During quiet stance, the orientation of the motion sensors was aligned to the reference axes of the transmitter.

Testing order for the FR and LOS tests was randomized across participants. A detailed description of the LOS procedures is provided elsewhere (Clark et al., 1997; NeuroCom International, 2001). In brief, a video screen was positioned on a shelf immediately in front of and at eye level of the participant. On the video display were eight visual targets arranged in a circular fashion at 100% of the participant’s theoretical stability limits and a cursor that provided concurrent visual biofeedback of the participant’s COG position. Before testing, participants completed a 1-min familiarization period during which they explored the relationship between changes in body position and movements of the on-screen COG cursor. After this familiarization period, participants were instructed to position the COG cursor in the target located in the center of the screen (i.e., approximately zero COG excursion) and to maintain an upright position with arms resting by their sides at all times. Participants were then told that after receiving the verbal command “lean” they were to “try to position the cursor in the top target or as close to it as you can by leaning forward as far as possible without losing balance or taking a step.” Participants completed two practice and three test trials of leaning forward toward the anterior test target. If a participant lost balance or took a step, data were discarded and the trial was repeated.

For the FR test, participants stood on the Balance Master force platform in the standardized foot position, and COG excursion was monitored as it was for the LOS, but the visual biofeedback was eliminated. Rather, a standard yardstick was attached to the wall, parallel to the floor, at the height of the subject’s right acromion. Participants were asked to make a fist with their right hand and to raise their arm with elbow extended until their fist was at the height of the yardstick. Once their
arm was level to and parallel with the yardstick, the participants’ upright position was adjusted manually, if necessary, to ensure that the COG cursor was located in the center target (i.e., approximately zero COG excursion). Participants were then instructed to “reach as far forward as possible without losing balance or taking a step.” During FR performance, projected COG excursions were recorded using the Balance Master system, and the linear displacement of the third metacarpal was recorded using the Skill Technologies 6-D research system. Similar to the LOS, participants completed two practice and three test trials of the FR. If a participant lost balance or took a step, data were discarded and the trial was repeated.

DATA ANALYSES

Postural strategies during the FR and LOS trials were assessed using a cross-correlation analysis of trunk and lower leg angular-displacement data (Bardy, Marin, Stoffregen, & Bootsma, 1999; Lekhel, Marchand, Assaiante, Cremieux, & Amblard, 1994; Stoffregen, Adolph, Thelen, Gorday, & Sheng, 1997; Wernick-Robinson et al., 1999). Data used in the analysis included the 5 s of angular motion following the initiation of the lean (Wernick-Robinson et al.). Cross-correlation analysis provided a measure of the relative phase relationship between motions of the upper and lower body in the sagittal plane during the leaning tasks. Strong, negative cross-correlation values reflect an antiphase relationship between the upper and lower body segments typified by trunk flexion and ankle plantar flexion. As previously reported, this postural strategy is indicative of a hip strategy (Bardy et al.; Lekhel et al.; Stoffregen et al.; Wernick-Robinson et al.). In contrast, strong, positive cross-correlation values reflect an in-phase relationship between upper and lower body motions. This strategy typically includes trunk flexion with ankle dorsiflexion and is indicative of an ankle strategy (Bardy et al.; Lekhel et al.; Stoffregen et al.; Wernick-Robinson et al.). Before statistical analyses, Fisher Z transformations were performed on the cross-correlation values obtained from each test trial. Weighted averages were then determined for both the FR and LOS tests using the three transformed values from each test. These weighted averages represented the mean cross-correlation values for the FR and LOS tests and were used in multivariate, repeated-measures analysis of variance.

Postural limits during the FR and LOS performance were assessed using the maximum COG-excursion value determined by the Balance Master system. The derived COG-excursion value indicated the farthest anterior position of the COG during the test trial. This value reflects the participant’s self-perceived postural limit and is expressed as a percentage of their theoretical maximum COG displacement (i.e., relative to their 100% limits of stability; NeuroCom International, 2001). The mean COG-excursion values from the three test trials for both the FR and LOS tests were used in the data analyses. In addition, during each of the FR trials, a FR score was determined from the linear kinematic data. This FR score reflected the maximum anterior displacement of the third metacarpal during forward reaching. The mean FR score from the three trials was used in the data analyses.
To determine whether there were differences in postural strategies or limits during performances on the LOS and FR tests, a multivariate repeated-measures analysis of variance was performed using the following variables: cross-correlation coefficients and maximum COG excursions. The relationship between FR performance (FR score) and maximum COG excursion during the LOS test was assessed using a Pearson correlation. The alpha level of significance for all analyses was set at $p \leq .05$.

## Results

Descriptive statistics for the dependent variables are presented in Table 1. Results of the repeated-measures multivariate analysis of variance indicated that performances on the FR and LOS tests were significantly different, Wilks’s $\Lambda = .42$, $F(2, 12) = 8.94$, $p < .01$. Follow-up univariate tests revealed that this observed difference was attributed to measured differences in both cross-correlation coefficients, $F(1, 13) = 7.35$, $p = .02$, and maximum COG excursions, $F(1, 13) = 6.34$, $p = .03$. A comparison of cross-correlation coefficients indicated that participants tended to use strategies that were less out of phase on the LOS test than those employed during the FR test. Although significant differences were observed when comparing postural strategies between the two tests, the relatively large cross-correlation-coefficient standard deviations suggest that individuals adopted a variety of strategies when performing both the FR and the LOS (see Table 1). Variations in strategy were particularly notable on the LOS test, where cross-correlation values ranged from antiphase to strongly in phase.

Observed differences in maximum COG excursion were attributed to the COG position being approximately 10% farther through the stability region on the LOS test than on the FR test. Effect-size calculations for differences between FR and LOS were moderate (.50) and indicated that maximum COG-excursion values for the LOS were approximately half a standard deviation higher than those for the FR (Cohen, 1988). An examination of the relationship between the FR score and the maximum COG excursion on the LOS test revealed a nonsignificant Pearson correlation coefficient ($r = .274$, $p = .343$).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Cross-Correlation Coefficient$^a$</th>
<th>Maximum COG Excursion$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Functional reach</td>
<td>$-0.79$</td>
<td>0.36</td>
</tr>
<tr>
<td>Limits of stability</td>
<td>$-0.37$</td>
<td>0.69</td>
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</tbody>
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*Note. COG = center of gravity.*

$^a$Indicative of strategy, expressed as the correlation coefficient at zero lag. $^b$Expressed as a percentage of the theoretical maximum COG excursion.
Discussion

Findings from the present investigation indicated that healthy older adult performance as determined by postural strategies and maximum COG excursions differed for the FR and LOS tests. In addition, results support the findings of Wallmann (2001) that FR-test scores have a poor correlation with maximum COG-exursion values during anterior target testing on the LOS. Thus, despite the relatively similar instructions to reach or lean as far as possible without losing balance or altering the base of support, older adult participants both tended to adopt more of an in-phase postural strategy and produced greater COG excursions through their stability region when comparing LOS test performance with that of the FR test.

When performing reaching or leaning activities, individuals coordinate body segments in multiple ways in order to both maintain postural stability and achieve task goals (Nashner & McCollum, 1985; Riccio & Stoffregen, 1988). Statistical differences in maximum COG excursion and in cross-correlation values between the upper and lower body motions during FR and LOS performance seem to indicate that strategies adopted by participants to achieve self-perceived maximal reach during the FR (more hip-like than ankle-like) might not have been as effective in producing maximal COG excursions as were strategies used during the LOS (more ankle-like than hip-like). This is consistent with the suggestion of Wallmann (2001).

Observed differences in FR and LOS performance with regard to postural limits might be attributed to participants using the COG biofeedback during the LOS to explore and identify effective movement strategies. Previously published findings from biofeedback-based balance interventions indicate significant improvements in selected measures of postural control, including greater movement velocities of the COG through an expanded region of stability (Rose & Clark, 2000), reduced standing sway (Shumway-Cook, Anson, & Haller, 1988; Wolf, Barnhart, Ellison, & Coogler, 1997), and improvements in achieving symmetrical stance (Walker, Brouwer, & Culham, 2000; Weinstein, Gardner, McNeal, Barto, & Nicholson, 1989). Because biofeedback provides relevant information that individuals are able to use in order to modify or correct errors in movement performance (Rose, 1997), participants in the present study might have used movement of the COG cursor to determine the effectiveness of movement strategies during LOS performance and modified their actions accordingly.

Another plausible explanation for the study’s findings is that individuals manage conflict between task and mechanical constraints differently for the two tests. During reaching and leaning tasks, postural limits are influenced by a person’s willingness to tolerate biomechanical instability for the achievement of task goals (Riley, Mitra, Stoffregen, & Turvey, 1997; Robinovitch, 1998). When reaching or leaning, the COG moves away from being centered over the base of support, creating a destabilizing torque that threatens postural stability. The use of an extrinsic, achievable task goal in the form of visual target during the LOS might have encouraged participants to tolerate greater biomechanical instability
in order to achieve the stated goal of placing the cursor in or close to the target. In contrast, the FR provided participants with a self-imposed task goal, to reach as far as possible. An unwillingness to compromise biomechanical stability might have resulted in maximal reach being attained with smaller COG excursions. Participants performing the FR might have reduced destabilizing torques by employing movement strategies that minimized COG excursions (e.g., shoulder protraction, hip strategy) or by relaxing task goals (e.g., decrease in reaching distance; Jonsson et al., 2003; Wernick-Robinson et al., 1999).

A possible limitation of this study was that participants might have had orthopedic impairments that were not identified in the prestudy screening but negatively affected balance or test performance. The screening questionnaire inquired about permanent orthopedic impairments but might have missed individuals who experienced loss of upper body or shoulder flexibility, low back pain, or increased stiffness in lower extremity joints. In addition, hand dominance or preferred limb was not considered when performing the FR test.

Although the FR and LOS tests are widely used in clinical and research settings to evaluate relative fall risk among older adults, these tests provide different estimates of postural limits as determined by maximum COG excursions. Results from the present investigation together with previously reported findings of poor correlations between FR and LOS measures (Wallmann, 2001) indicate that practitioners should not assume that these clinical tests of balance can be used interchangeably. Practitioners using the FR should be aware that self-perceived postural limits for this test generally underestimated older adults’ postural limits when compared with LOS performance. It is suggested that difference between the FR and LOS might be attributed to differences in task constraints for these tests. Adapting the FR to include an overt task goal, such as an object to be touched, intuitively would provide incentive for tolerating greater biomechanical instability while simultaneously increasing the functional nature of the reaching task (Rose, 2003). Future investigations examining the use of an overt task goal during reaching or leaning tasks are warranted. Recommendations for further research also include expanding on the present investigation to compare postural strategies and maximum anterior COG displacements during FR and LOS performance in older adults at risk for falls or individuals with identified pathologies.

References


