A Clinical Test of Stepping and Change of Direction to Identify Multiple Falling Older Adults

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Objectives: To establish the reliability and validity of a new clinical test of dynamic standing balance, the Four Square Step Test (FSST), to evaluate its sensitivity, specificity, and predictive value in identifying subjects who fall, and to compare it with 3 established balance and mobility tests.

Design: A 3-group comparison performed by using 3 validated tests and 1 new test.

Setting: A rehabilitation center and university medical school in Australia.

Participants: Eighty-one community-dwelling adults over the age of 65 years. Subjects were age- and gender-matched to form 3 groups: multiple fallers, nonmultiple fallers, and healthy comparisons.

Interventions: Not applicable.

Main Outcome Measures: Time to complete the FSST and Timed Up and Go test and the number of steps to complete the Step Test and Functional Reach Test distance.

Results: High reliability was found for interrater (n=30, intraclass correlation coefficient [ICC]=.99) and retest reliability (n=20, ICC=.98). Evidence for validity was found through correlation with other existing balance tests. Validity was supported, with the FSST showing significantly better performance scores ($P<.01$) for each of the healthier and less impaired groups. The FSST also revealed a sensitivity of 85%, a specificity of 88% to 100%, and a positive predictive value of 86%.

Conclusion: As a clinical test, the FSST is reliable, valid, easy to score, quick to administer, requires little space, and needs no special equipment. It is unique in that it involves stepping over low objects (2.5cm) and movement in 4 directions. The FSST had higher combined sensitivity and specificity for identifying differences between groups in the selected sample population of older adults than the 3 tests with which it was compared.

Key Words: Accidentals falls; Balance; Elderly; Rehabilitation; Reliability and validity.

THIRTY PERCENT OF ALL community-dwellers at or over age 65 years fall at least once each year.[1-4] This percentage is even higher for women and older adults with neurologic or musculoskeletal disorders.[5-8] Among older adults, the consequences of falling include 31% to 48% having a fear of falling,[1,4,9,10] 19% to 26% reducing activity levels,[1,11,12] and fall injuries occurring in 46% to 60% of all falls.[1,2,11,13,14] Serious injuries have been found to occur in 6% to 14% of falls.[1,11,13,14] Deaths from falls also occur for people over the age of 65 years, with 1 study[15] finding 2.2 deaths occurring for every 100 fall-injury events admitted to acute medical facilities.

Falls are associated with multiple risk factors and increase with a rise in the number of risk factors.[6,8,16] One frequently reported and consistently identified risk factor is impaired balance and mobility.[4,8,17,18] For a person with a balance and mobility deficit, restoring function or preventing further dysfunction are priorities for health care providers. To perform this rehabilitation service effectively, one must be able to identify the impairment, to provide appropriate treatment, and to evaluate outcomes using assessment tools with known measurement properties.

Because of the multifactorial nature of balance and mobility a single all-encompassing measurement cannot exist. A range of balance test options is required (1) to assess the widely varied demands of human movement during activities of daily living and (2) to identify specific aspects of balance impairment. As a result, an extensive range of tests has been developed for use in the clinical setting. The choice of test will depend on a number of factors. Clinicians must consider the tests' measurement properties, characteristics of the population being tested, expertise required to administer the test, cost and equipment requirements, as well as the time and space demands of the test.

Some aspects of balance and mobility present unique balance problems to the older adult population and have received little measurement attention. One such aspect is the ability of older adults to step quickly in different directions. Most falls occur during movement, with trips and slips being identified as the most common reasons why an older adult has fallen.[19,20] Trips account for between 40% to 60% of falls[5,13,21] and slips between 10% to 15% of falls,[13,21] indicating that the ability to take a rapid step would avert many falls. The Step Test[22] is a clinical test developed to assess a person's ability to step rapidly in the forward direction. However, previous research has found stepping speed in the forward, backward, and sideway directions decreases with age[23] and is slower for fallers than for nonfallers.[24]

Medell and Alexander[24] developed a clinical measure of rapid stepping in 3 different directions. This test involves measuring the maximal step length for the subject and marking a distance on the floor at 80% of his/her maximal step length. On the tester's command, subjects step 4 times in 1 direction, returning each time to the initial standing position. The direction of stepping is randomly ordered, and both legs are tested. A potential limitation to the clinical use of this test is the time required to measure and mark out the step distances.

A new clinical measure of rapid stepping and obstacle avoidance, the Four Square Step Test (FSST), was evaluated between March 1999 and July 2000. This test requires subjects to

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rapidly change direction while stepping forward, backward, and sideway, over a low obstacle, while time to complete the test is measured. One aim of the present study was to document the validity and reproducibility of the FSST and to establish its degree of concurrence with the Timed Up and Go[25] (TUG) test, Functional Reach Test (FRT),[26] and Step Test.[2] A second aim was to compare the FSST's ability to discriminate subgroups of fallers with that of the TUG, FRT, and Step Test. The TUG, FRT, and Step Test are reliable and valid measures and have previously been reported in the literature. The ability to discriminate between older adult fallers and nonfallers has been found for the TUG[27] and FRT.[28] The Step Test's ability to identify differences between older adult fallers and nonfallers has not been reported, however, it was found to discriminate between healthy adults and groups with various neurologic impairments.[22,29,30] All 3 tests feature self-initiated movement by the participants, meet the measurement requirements needed for use in the clinical setting, and measure different aspects of balance. The TUG measures the time taken to stand from a chair, walk 3m at a comfortable pace, turn, walk back to the chair and sit down. The FRT identifies the maximum distance a subject can reach forward without moving his/her feet. The Step Test measures the number of times in 15 seconds that a subject can step the same foot onto a step without moving the other foot.

METHODS

Participants

Eighty-one community-dwelling adults over the age of 65 years were tested. Fifty-four subjects were outpatients attending Community Rehabilitation Programs (CRP) at Bundoora Extended Care Centre, Austin & Repatriation Medical Centre or Royal Talbot Rehabilitation Centre (RTRC). Subjects were categorized either as multiple fallers (n=27; mean age ± standard deviation, 74.00±5.68y) who had 2 or more falls in the last 6 months or as nonmultiple fallers (n=27; mean age, 73.78±6.09y) who had fewer than 2 falls in that time frame. An additional 27 subjects (mean age, 74.14±6.07y) were recruited through community groups and through colleagues, friends, and family contacts to form a comparison group. The 3 groups were matched for age (±2y) and gender. Comparison subjects had to be active, and have no known neurologic or orthopedic condition affecting their balance or mobility. All subjects were (1) able to follow simple instructions and had a functional command of English, (2) able to give informed consent, (3) able to ambulate inside under close supervision, with or without a cane, for a distance of 6m, (4) not visually impaired, and (5) living in the community (not in supported accommodation). Subjects from all groups were recruited between January 14, 1999 and July 12, 2000. Ethics approval was obtained from the human research ethics committees of Austin & Repatriation Medical Centre, Bundoora Extended Care Centre, and RMIT University.

Subject Loss

A total of 127 subjects were initially recruited. Twenty-four subjects were unable to attend a testing session for the following reasons: difficulty understanding English (n=3), medical reasons (n=4), unable to arrange transport to testing facility (n=7), and desire not to be tested (n=10). Of the 103 subjects tested, 33 were multiple fallers, 39 were nonmultiple fallers, and 31 were comparisons. Twenty-two of these subjects could not be matched for age and gender and were excluded from the study. No other subjects initially recruited were excluded, and all of the 81 subjects included were able to complete all of the balance tests successfully.

Table 1: Number and Type of Medical Conditions for CRP Subjects

	Multiple Faller (n=27)	Nonmultiple Faller (n=27)
Hypertension	13	9
Arthritis	8	9
Stroke	8	6
Total hip or knee replacement	5	8
Other medical	11	7
Other cardiovascular	6	11
Other neurologic	6	3
Other orthopedic	5	5

NOTE: There were 14 women and 13 men in each group.

Procedures

Prior to testing, all CRP subjects obtained medical clearance from their local doctors. Previous medical conditions for each subject and any current visual impairment were provided as part of this medical clearance (table 1). Testing for the study was then performed during the 1 visit at either RMIT University or the RTRC. In both settings, a large, open-floor plan gymnasium with a wooden floor was used. Subjects were first interviewed by using a formatted questionnaire. This interview was used to obtain details of living arrangements, gait aids used, self-perceived health, balance and activity levels, and a self-reported fall history over the previous 6 months. This fall history determined subject fall classification. Subjects were classified as a multiple faller if they had 2 or more falls in the previous 6 months. A fall was considered any unintentional contact of a body part, other than the feet, onto a lower surface or onto the ground. Falls caused by an overwhelming environmental hazard, acute illness, or syncope were excluded.[1,3,4] After this interview, subjects completed the Mini-Mental State Examination[31] (MMSE) and were then assessed on the 4 balance and mobility measures. Table 2 provides the results of the subject interviews and the MMSE. During the physical assessments, subjects were permitted to rest as required, and a refreshment break was provided for all subjects following completion of the tests or during testing if required. Subjects were randomly assigned to 1 of 4 groups for test order. A counterbalanced design was used to control the order effects of learning and fatigue associated with the tests administered.

Rating Procedure for Retest Reliability

After completing of all tests, subjects were asked if they would be interested in returning 1 week later to be retested on the FSST. The first 20 subjects willing to do this were then tested a second time. The results of these 2 FSST scores were used to evaluate the test-retest reliability of the FSST. Eleven nonmultiple fallers with a mean age of 70±4.78 years and 9 multiple fallers with a mean age of 73±6.07 years participated in the retest reliability study. When possible, subjects participating in the retest reliability phase were tested at weekly intervals, a common retest interval for reassessment.[30] The number of days between test and retest ranged from 1 to 21, with a mean of 7.55±5.96 days.

Test Administration

All research assistants who administered and scored the balance and mobility measures were blinded to subjects' inter-

Table 2: Profile of the Age- and Gender-Matched Study Sample

		Multiple Faller (n=27)	Nonmultiple Faller (n=27)	Comparison (n=27)
MMSE score	Median (IQR)	28 (25.7–30)	29 (25–30)	
Living arrangement	Alone	7 (26)	5 (19)	7 (26)
	With others	20 (74)	22 (81)	20 (74)
Health rating*	Good-excellent	16 (59)	22 (81)	27 (100)
	Fair	9 (33)	5 (19)	
	Poor-bad	2 (8)		
Balance rating*	Good-excellent	4 (15)	18 (67)	27 (100)
	Fair	18 (67)	8 (29)	
	Poor-bad	5 (18)	1 (4)	
Daily activity*	>60min	7 (26)	17 (63)	27 (100)
	30–60min	18 (67)	6 (22)	
	<30min	2 (7)	4 (15)	
Gait aid inside†	None	16 (59)	24 (89)	27 (100)
	Cane	11 (41)	3 (11)	
Gait aid outside†	None	7 (26)	15 (56)	27 (100)
	Cane	16 (59)	10 (37)	
	Wheelie frame	4 (15)	2 (7)	

NOTE. Scores are frequencies (percentage), unless otherwise stated.
* Self-perceived rating.
† Includes occasional use of gait aid.

view results, fall history, and medical background. One research assistant and the principal investigator independently and simultaneously timed the first 30 subjects to perform the FSST. The results from these scores were used to calculate the interrater reliability of the FSST. Test administrators (examiners) were 5 physiotherapists from RTRC and 1 research assistant currently undertaking a doctoral-level degree through RMIT University. Each examiner was given a demonstration of the FSST and a practice scoring trial. All examiners were familiar with the TUG, FRT, and Step Test. Subjects were assessed by the same examiner for all 4 of the balance tests.

Test Description

The equipment required for the FSST includes a stopwatch and 4 canes. The square is formed by using 4 canes resting flat on the floor. Canes were 90cm long, and the direction and type of handle used is not important (fig 1). The subject stands in square number 1 facing square number 2. The aim is to step as fast as possible into each square in the following sequence. Square number 2, 3, 4, 1, 4, 3, 2, and 1. This sequence requires the subject to step forward, backward, and sideway to the right and left. The score is recorded as the time taken to complete the sequence. The stopwatch starts when the first foot contacts the floor in square 2 and finishes when the last foot comes back to touch the floor in square 1. The following instructions are given to the subject, "Try to complete the sequence as fast as possible without touching the sticks. Both feet must make contact with the floor in each square. If possible, face forward during the entire sequence." The sequence is then shown to the subject. One practice trial is completed to ensure the subject knows the sequence. Two FSST are completed with the best time taken as the score. A trial is repeated if the subject fails to complete the sequence successfully, loses balance, or makes contact with a cane during the sequence. Subjects who were unable to face forward during the entire sequence and needed to turn before stepping into the next square were still given a score. All subjects wore their preferred shoes. The examiner stood in a position to see all steps taken by the subject, and an assistant provided the subject with close supervision. The entire test, including giving instructions and a practice trial, took less than 5 minutes to complete.

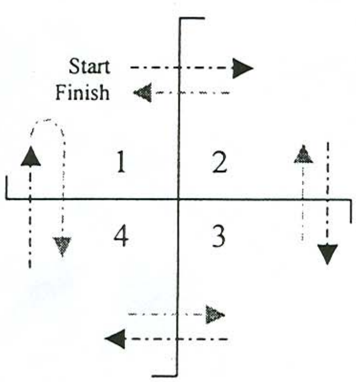

Figure 1. FSST set-up. The subject starts in square 1, facing square 2. The subject steps forward into square 2, sideway to square 3, backward to square 4, sideway to square 1, sideway to square 4, forward to square 3, sideway to square 2, and backward to square 1.

Statistical Analysis

Intraclass correlation coefficients (ICCs) were used to evaluate intrarater and retest reliability of the FSST. Differences between the 3 groups for FRT distances were examined using 1-way analysis of variance (ANOVA). Post hoc analysis using the Tukey B procedure was used to identify specific group differences. Between-group differences for measures that were not normally distributed (FSST, TUG, Step Test) were examined by using the Kruskal-Wallis 1-way ANOVA, with the multiple comparison procedure used to identify specific group differences.[32] Alpha was set at .05. Because of the large number of comparisons, we used the Bonferroni correction. Differences were considered significant if P was less than .004 (.05/12). Because of the lack of normally distributed variables, correlations were reported as Spearman ρ. We calculated sensitivity and specificity for the FSST, TUG, FRT, and Step Test.

Table 3: Balance and Mobility Assessments Result for Each of the 3 Groups

Test	Multiple Faller (n=27)	Nonmultiple Faller (n=27)	Comparison (n=27)
FSST (s)	23.59 (18.9–29.7)	12.01 (9.75–14.69)	8.70 (7.36–10.01)*
Step Test	7.00 (5.0–9.0)	11.00 (9.0–14.0)	16.00 (14.0–19.0)*
TUG (s)	16.68 (14.93–22.12)	12.31 (9.75–14.69)	10.00 (9.32–11.0)†
FRT (cm)	21.00 (15.0–26.0)	26.00 (19–29)	32.00 (28.0–36.0)‡

NOTE: Values are median (IQR).
* Significant difference between all 3 groups.
† Significant difference between multiple faller and the other 2 groups.
‡ Significant difference between multiple faller and comparison groups.

Sensitivity was reported as the percentage of multiple fallers being correctly classified and specificity as the percentage of nonmultiple fallers and comparisons correctly identified. The cutoff score for all of the balance tests was chosen to maximize both sensitivity and specificity. Predictive value positive reflects the probability that the scoring above the cutoff correctly identified multiple fallers and predictive value negative reflects the probability that the nonmultiple fallers and comparisons were correctly identified as nonfallers by scoring at or below the cutoff.

RESULTS

Test Order Results

To account for a possible practice or learning effect between balance tests or a fatigue effect as the result of testing, subjects were randomly assigned into 1 of 4 test order groups. The Kruskal-Wallis 1-way ANOVA by ranks found no significant differences between test order groups on any of the balance and mobility measurements (FSST: $\chi^2_3=2.09$, $P=.55$; TUG: $\chi^2_3=4.84$, $P=.18$; Step Test: $\chi^2_3=.89$, $P=.59$; FRT: $\chi^2_3=2.75$, $P=.43$).

FSST Reliability and Group Performance on Balance and Mobility Measures

Excellent reliability for the FSST was found for interrater (n=30, ICC=.99) and retest reliability (n=20, ICC=.98). The median and interquartile range (IQR) for each balance and mobility measure is reported in table 3. Median and IQRs are reported because the FRT was the only normally distributed variable (Kolmogorov-Smirnov-Lilliefors >.05). Because the Step Test provides 2 scores (right and left legs), distinguishing between groups on this measurement was based on the lower score obtained by each subject. This method of comparison for the Step Test has been used by its designer.[4] A Wilcoxon signed-rank test revealed no significant difference between scores on the right and left legs ($z=-.865$, $P=.387$).

The Kruskal-Wallis 1-way ANOVA by ranks identified significant differences between groups on all tests (FSST: $\chi^2_2=57.20$, $P<.001$; TUG: $\chi^2_2=39.92$, $P<.001$; Step Test: $\chi^2_2=40.96$, $P<.001$). Significant differences were found between all 3 groups for the FSST and Step Test. For the TUG, significant differences were found between the multiple fallers and the other 2 groups. These results are summarized in table 3. In all the measurements, the pairwise difference was greatest between the multiple faller and the comparison groups. During testing, 4 multiple fallers and 1 nonmultiple faller used a cane as an assistive walking device during the FSST and TUG.

Differences among the 3 groups on the FRT were examined by means of a 1-way ANOVA. A significant difference was found between the groups ($F_{2,78}=10.46$, $P<.001$). Post hoc analysis revealed a significant pairwise difference between the multiple fallers and the comparison group. No other pairwise differences were found.

Significant correlations ($P<.001$) were found between all of the measures evaluated (table 4). Strong correlations were found between the FSST, Step Test, TUG ($r_s=-.79$ to .88). Lower correlations were found between the FRT and the other 3 measures ($r_s=-.47$ to .50).

Sensitivity, specificity, and predictive value. With all of the tests evaluated, the aim was to maximize sensitivity while maintaining specificity at an acceptable level. The cutoff scores (table 5) represent the optimal result for this study. An optimal cutoff score for the FSST of 15 seconds was identified. Subjects with scores of greater than 15 seconds were considered as multiple fallers and those with scores ≤15 as nonmultiple fallers. At 15 seconds, the FSST has a positive predictive value of 86% and a negative predictive value of 94% for the sample tested.

DISCUSSION

The FSST was found to have excellent interrater and retest reliability. Evidence for validity of the FSST was found through its strong correlations with the TUG and Step Test. The lower correlations found between the FSST and FRT were expected because the FRT measured a different aspect of balance than the tests that involved stepping. The FRT was the only measure used in this study that did not involve movement of the feet. The FSST identified significant differences between the 3 groups tested and had the highest combined sensitivity and specificity values of the balance measures used. These findings provide further support for the validity of the FSST.

The Step Test identified significant differences between the 3 groups tested. The TUG and FRT were able to discriminate between the multiple fallers and the other groups, although they could not identify differences between nonmultiple fallers and comparisons. It is difficult to adequately interpret the between group findings for the FRT. Subject height affects the FRT scores,[26] but this factor was not recorded in the present study. The requirement of the Step Test and FSST that subjects step as rapidly as possible enabled us to identify group differ-

Table 4: Correlation Matrix (Spearman ρ) for the Balance and Mobility Measures

	FSST	Step Test	TUG
Step Test	−.83		
TUG	.88	−.79	
FRT	−.47	.50	−.47

NOTE. All correlations significant at $P<.001$.

Table 5: Specificity and Sensitivity Results Comparing the Multiple Fallers to the Other 2 Groups

	Cutoff	Multiple Faller Sensitivity (%)	Nonmultiple Faller Specificity (%)	Comparisons Specificity (%)
FSST	>15s	89	85	100
TUG	>13s	89	67	93
Step Test	<11	81	63	96
FRT	<25cm	63	59	96

ences between the active, healthy comparisons and the nonmultiple fallers.

The scores obtained for the Step Test, TUG, and FRT for the present project were in agreement with scores obtained in previous research. Studies using samples of healthy volunteers have reported Step Test scores for left and right legs of 17.4 and 17.5,[22] and 16.1 and 16.3,[13] respectively. For the current study, the mean comparison group's Step Test scores for left and right legs were 16.3 and 16.4. The results from these studies of healthy older adults were remarkably close, despite differences in study samples. The first study cited used a slightly younger starting age of 60 years,[22] whereas the second study sample were all women, and all subjects were age 70 years or older.[13] One limitation to generalizing these findings is that all 3 studies used volunteer subjects. However, the similar results strengthen confidence in the normal values for Step Test scores for healthy community-dwelling older adults. TUG times for community-dwelling, healthy older adults have ranged from 8.4 to 15 seconds,[4,25,27,33,34] and the TUG time of 10 seconds for the comparison group found in the present study supports these findings. The sensitivity and specificity values we found for the TUG were also in agreement with results reported in the literature. Shumway-Cook et al[27] found that a cutoff score of 13.5 seconds for the TUG achieved a sensitivity of 87% for multiple fallers and a specificity of 87% for healthy comparisons. The present project found that a cutoff score of 13 seconds resulted in a sensitivity of 89% and a specificity of 93%. Both projects involved community-dwelling volunteers, compared the same groups, and used the same fall classification. FRT distances reported in the literature for community-dwelling day patients and fallers have ranged from 22.2 to 23.9cm.[4,28,35] The multiple faller group in the present project had a mean FRT measure of 22.8cm. FRT distances for healthy and active community-dwelling older adults have ranged from 30.7 to 36.8cm.[4,36] A mean FRT distance of 33cm was found for the comparison group in the present project.

The FSST was developed to incorporate a greater complexity of stepping than was available in the existing clinical balance tests. A key component of the test was to assess the subjects' ability to rapidly transfer weight during this stepping sequence. Another test developed to evaluate the rapid transfer of weight during a stepping task was the Step Test.[22] Although the Step Test was developed for a different population (stroke) and has subject safety during rapid stepping as a key goal, both tests were useful for evaluating subjects in the present project. Several key differences exist between the FSST and the Step Test. In the FSST, subjects may use a cane, the test incorporates stepping in different directions, it is more cognitively demanding (remembering sequence), and it involves multiple and complete transfer of weight between feet while changing direction. These differences may represent advantages or disadvantages, depending on the aspects of balance or the population being tested. The major disadvantages of the FSST are the higher level of skilled physical supervision required by the tester and the inability to award a score if the subject cannot complete the test.

CONCLUSION

The objective of the study was to establish the reliability and validity of a new clinical test of dynamic standing balance, the FSST, and to evaluate its sensitivity, specificity, and predictive value in identifying subjects who fall. The FSST was both sensitive and specific and had higher combined sensitivity and specificity than the 3 tests with which it was compared for identifying differences between groups in the selected sample population of older adults. The FSST also had excellent positive and negative predictive values. As a clinical test of dynamic standing balance, it is easy to score, quick to administer, and requires little space and no special equipment. It is unique in that it involves stepping over low objects (2.5cm); forward, backward, and sideway stepping; and rapid changes in movement direction. Because of these attributes, administering the FSST requires skilled physical supervision. The complexity of the stepping sequence may also make the FSST an inappropriate test for persons with cognitive impairment who cannot follow the test instructions. All subjects in the present study were able to complete the test successfully. Because the FSST is new, further research is required to assess its use in different diagnostic and age groups. The ability of the FSST to evaluate changes in performance over time or after therapeutic intervention also requires investigation. In particular, the challenging nature of the FSST may make it a particularly useful balance test for populations who are younger and for persons who have less pronounced deficits of dynamic standing balance. The results found in this project also provide support for the TUG, FRT, and Step Test and strengthen confidence in the normal values for these tests in both the healthy, active, community-dwelling elderly and those with an increased fall risk.

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