Journal of Gerontology: MEDICAL SCIENCES
2000, Vol. 55A, No. 8, M469–M476

A Prospective Study of Laboratory and Clinical Measures of Postural Stability to Predict Community-Dwelling Fallers

Sandra G. Brauer, Yvonne R. Burns, and Prudence Galley

Department of Physiotherapy, University of Queensland, St. Lucia, Australia.

Background. The identification of specific risk factors for falls in community-dwelling elderly persons is required to detect early changes and permit a preventative approach to management. This study determines the ability of various laboratory measures and clinical tests of postural stability to prospectively predict fallers in community-dwelling elderly women.

Methods. One hundred elderly women (65–86 years, mean age 73 $\pm$ 5 years) performed a reaction-time step task, a limits of stability, and a quiet stance balance task. Postural muscle timing and movement speed were recorded during the step task. Center of pressure (COP) motion was recorded in quiet stance and at the limits of stability. Four common clinical balance tests were performed, and balance confidence, medical and activity history questionnaires were completed. Subjects were followed up regularly for a 6-month period following testing to determine the frequency and characteristics of any falls that occurred. Predictive capabilities of the balance measures to determine fallers were determined through logistic regression models.

Results. The clinical balance tests investigated were not able to predict fallers in this community-dwelling elderly population. A combination of variables from the laboratory tasks provided the best overall prediction rate (77%) of fallers (sensitivity 51%) and nonfallers (specificity 91%) from laboratory measures. Of these, step movement time and gluteus medius onset times were the factors best able to predict fallers. Alone, measures of COP motion in quiet stance and at the limits of stability had a poor ability to predict fallers, although they could correctly identify most nonfallers. Prediction was not significantly improved when clinical balance test results were added to the most predictive laboratory measures.

Conclusions. Not all older adults with a reduction in balance ability reported a fall over a 6-month period. Of those who did, a combination of measures reflective of different aspects of mediolateral postural stability during a rapid step task, quiet stance, and movement to the limits of stability were best able to predict faller status, with nonfallers better predicted than fallers. These results emphasize the importance of the multifactorial nature of falls in the community-dwelling elderly population in that the clinical and laboratory measures did not predict a high proportion of fallers.

DURING a 1-year period, approximately 35% of adults aged over 65 years are estimated to fall (1–3), with this rate greater in women (4) and increasing with age (3). Although less than 10% of falls are reported to result in significant physical injury (5,6), they can lead to a fear of falling and a self-imposed restriction of physical activity, which can further increase the risk of falling (7,8). Many risk factors for falls have been identified, with balance impairment frequently reported as a risk factor that has the potential to be influenced with intervention (8,9). The ability to predict who is at risk of falling is required to enable a preventative approach to the problem of falls in the elderly population.

Some clinical tests of balance performance have been demonstrated to predict elderly fallers. Fallers have been predicted by low scores on the Berg Balance Scale (9,10) and the Tinetti Balance subscale (2,11), and by a short anterior reach distance in stance (12). They have also been predicted by poor performance on functional tasks such as picking up an object from the floor (13), moving from a sitting to standing position, inability to walk tandem, or descending stairs without a handrail (14). These studies have evaluated a variety of older adults who have differing residential arrangements (community-dwelling or institution residents) and varying levels of physical function. To enable earliest detection of deteriorated balance function, older adults with few comorbidities and who reside independently in the community need to be evaluated. Although several groups have investigated the prediction of fallers in this population (1,9,13), the clinical balance test best able to predict fallers has not been determined. Thus, the first purpose of this study was to investigate the abilities of several clinical balance tests to predict community-dwelling elderly fallers and nonfallers.

Although clinical tests of balance function are able to provide an indication of balance abilities, they are limited in the ability to detect subtle changes in postural stability and identify mechanisms of dysfunction. Laboratory-based assessment can provide information regarding control processes and biomechanical changes relevant to balance. Several studies have used measures of body motion in quiet stance and found that increased body sway (1,15) and a large center of pressure (COP) area and amplitude to prospectively predict elderly fallers (11,16). Direction specificity of COP motion was reported by Maki and coworkers (16), who found that COP motion in the mediolateral (ML) direction best predicted fallers. These results indicated that a reduction in control of ML body motion, even during a minimally challenging task, may be associated with an increased risk of falling.

Considering most falls occur during a dynamic task (1,4) and clinical tests that predict elderly fallers have a dynamic component, evaluation of the control of a dynamic task which challenges ML stability may provide a better prediction of fallers than quiet stance COP motion. Thus, the second purpose of this study was to prospectively examine the ability of both dynamic and static laboratory measures to predict elderly community-dwelling fallers. We hypothesized that laboratory measures reflective of ML postural stability during a dynamic task would provide a better prediction of fallers than measures of static ability. We also hypothesized that there would be greatest differences between faller and nonfaller groups in the laboratory measures reflective of ML postural stability. The third purpose of this study was to determine if the addition of clinical balance tests would influence the prediction obtained with laboratory measures alone. We hypothesized that the best prediction of fallers will be obtained when clinical balance tests are added to the best laboratory predictors of falls.

Methods

Subjects

One hundred elderly female community-dwelling volunteers (65–86 years, mean age 71 $\pm$ 5 years) participated in the study. The sample size was selected to provide reasonably small confidence intervals on the estimated error rate in classifying subjects as fallers or nonfallers. It was estimated that a sample size of 92 would allow an actual misclassification rate of 0.3 to be estimated within a 95% confidence interval of $\pm$0.07 (17). Subjects were excluded from participating if they reported any of the following: (a) history of surgery on either lower limb, pelvis, or back; (b) neurological impairment; (c) known uncorrected visual or vestibular problems; (d) major musculoskeletal disorder; (e) significant pain that limited daily function; (f) an ear infection within 2 weeks prior to testing; and (g) a fall within the month prior to testing. Informed consent was obtained from all subjects. The study was approved by the Medical Research Ethics Committee of the University of Queensland.

Protocol

Each subject performed three laboratory tasks and four clinical balance tests in the same order during one session. Laboratory measures of postural stability were recorded during three tasks: (a) quiet stance, (b) moving to the limits of stability (LOS), and (c) a reaction-time step task. The quiet-stance task involved standing for 50 seconds with eyes open and 50 seconds with eyes closed. Subjects were instructed to stand still for this time, looking at a target placed 1 meter in front of them at eye level in the eyes-open situation. In the LOS task, subjects performed in random order, a maximal lean for 5 seconds to the right, left, anterior, and posterior directions while standing with feet 10 cm apart, each angled out 15 degrees. Subjects were instructed to keep the whole of both feet in contact with the ground at all times.

The reaction-time step paradigm involved the subject responding to *warning* and *response* lights by stepping the indicated leg (right or left) as fast as possible onto a step (15 cm high) placed in front of the feet, with a switch embedded beneath an inflexible surface (Figure 1). Subjects performed this at two levels of preparation (high and neutral) where there was an 80% and 50% chance, respectively, of receiving an instruction to step with the leg appropriate to the warning. A neutral preparatory set was included to better simulate unexpected voluntary movement, as may occur with overbalancing. Thirty trials of stepping with the left leg were recorded. Seated rest periods were permitted between trials and tests. Clinical balance tests were performed after the completion of the laboratory tasks. A self-reported medical and activity history was taken and mental status (Mini-Mental State Examination) (18) and balance confidence (Activities-specific Balance Confidence scale) questionnaires (19) were also completed.

Apparatus and Measurements

In all laboratory tasks, subjects stood with each foot on a force platform (MEUQ, The University of Queensland, St Lucia, Australia). In the quiet stance task, COP position, velocity, and amplitude (RMS) were recorded for 50 seconds in the anterior-posterior (AP) and mediolateral (ML) directions. Total distance traveled by the COP was also recorded for the 50 seconds. In the limits of stability task, the maximal COP position was recorded and expressed as a percentage

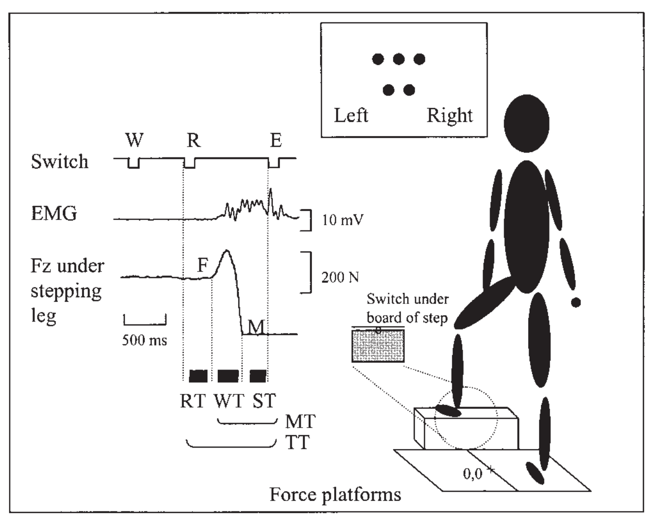

Figure 1. Measures taken from the switch, electromyogram (EMG), and the stepping leg vertical forces (Fz) during a rapid step. W = warning light; R = response light; E = end of movement, foot triggering switch in step on contact; F = start of weightshift where there is first increase in force under the steppping leg; M = point where stepping foot lifts off force platform (Fz under stepping leg = 0); RT = time from onset of response light to start of weightshift (F); WT = time from start of weightshift until complete foot off; ST = time from complete foot off until foot contact with the step; MT = time from start of weightshift until foot contact with the step; TT = time from onset of response light until foot contact with the step.

of the total foot length or width. In the step task, a surface electromyogram (EMG) was recorded from the stance side (right) gluteus medius and tensor fascia latae, and the step side (left) hip adductor muscle group (LHA) with self-adhesive electrodes placed in a bipolar configuration 10 cm apart along the line of the muscle fibers. Onset of muscle activity was determined where the activity rose 3 standard deviations (*SD*) above the baseline mean for at least 25 milliseconds. By using the lights, foot switch, and vertical force (Fz) under the stepping leg, the step task was divided into reaction time, weightshift time, step time, and movement time (Figure 1). All data were collected at 1000 Hz by an AmlabII data acquisition system (Associative Measurement Pty Ltd, Australia). The force platform data were reduced to 100 Hz and low-pass filtered at 10 Hz. The EMG data were full-wave rectified and filtered with a 50 Hz sixth order elliptical low-pass filter. Signal processing and data analysis were performed using Matlab (The Math Works, Natick, MA).

Clinical Tests

Four clinical tests of balance were performed by an experienced physiotherapist: the Berg Balance Scale (20), the Functional Reach Test (21), the Lateral Reach Test (22), and the Step-Up Test (23). The Berg Balance Scale is a battery of 14 functional tasks and has reported excellent intrarater and interrater reliability ($r = .91$). It has demonstrated concurrent validity by its correlation with other balance tests: the Tinetti Mobility Index ($r = .91$), the Timed Up and Go Test ($r = .76$), and the functional assessment inventory ($r = .86$) (24–27). The reach tests are measures of maximal anterior and lateral distances reached beyond arm's length in stance. The Step-Up Test (23) involves stepping one foot on and off a 15 cm high step as many times as possible in 15 seconds. All tests were performed bilaterally. High test-retest reliability has been reported in the Functional Reach Test ($r = .92$), the Lateral Reach Test ($r = .99$), and the Step-Up Test (21–23,28). To demonstrate validity, the reach tests have been significantly correlated with measurements of maximal COP excursion (Functional Reach, $r = .71$; Lateral Reach, $r = .33$), and the Step-Up Test has been correlated with Functional Reach (21–23,28).

Follow-Up Procedure

For follow-up, subjects were given a calendar for the 6 months following the test month and self-addressed envelopes to facilitate easy return of monthly pages. Subjects were asked to mark their calendars daily, recording any slips, trips, or falls. This study used the falls information only. A fall was defined as any event that resulted in coming to rest inadvertently on the ground or another lower level. At the end of the month, that calendar page was returned, and if any of these events were reported, the investigator telephoned the subject within the week to ascertain more information about the event. All subjects were telephoned at least twice in the follow-up period to maintain contact.

Falls were classified into five types based on the perturbation experienced prior to falling (29). The fall types included in this study were: base of support (BOS) falls, where a perturbation prevented the BOS from being realigned over the moving center of mass (e.g., tripping over a rug); center of mass (COM) falls, where the COM is displaced beyond the limits of the BOS (e.g., reaching out and overbalancing); and no obvious perturbation (NOP) falls (e.g., feeling faint and falling). Two fall types were not included in the falls group: hazard falls (the result of an unexpected external hazard, e.g., struck by a cyclist) and unclassifiable falls (e.g., the subject could not remember sufficient information to allow classification).

Statistical Analysis

To determine differences in demographic characteristics between groups, chi-square tests (for nominal data) and Mann-Whitney *U* tests (ordinal data) were performed. Between-group differences in all other measures (continuous data) were determined through analyses of variance tests. The criterion level of significance was set at 0.01 to reduce the chance of a Type 1 statistical error. To assess the predictive abilities of the balance measures, both direct and sequential logistic regression models were applied to the data, with fallers compared with nonfallers in each analysis. Sensitivity and specificity of each model was calculated. The sensitivity of the model was defined as the percentage of fallers who were correctly identified. Alternately, specificity was defined as the percentage of nonfallers that were correctly identified. In all models, the cutpoint probability level used in classifying the data was 0.5 and the significance level was set at $p < .01$. In all models, predictive accuracy was estimated using a cross-validation procedure.

Results

Frequency of Falls and Fallers

An excellent response rate was achieved, with a complete calendar record of 99 subjects for 6 months obtained. One subject died in her last month of follow-up. She was classified as a faller, as she had reported two falls in the months prior to death.

In total, 82 falls were reported in the 6-month period. Of these, two were the result of an external hazard and 14 were unclassifiable, leaving 66 falls that were included in the COM, BOS, and NOP fall categories. BOS falls comprised 63.6% (42 out of 66) of all included falls, 25.8% (17 out of 66) were COM falls, and 10.6% (7 out of 66) were NOP falls. Ten fallers reported only BOS falls, three fallers reported only COM falls, and the rest reported falls from all categories. Over the 6-month prospective monitoring period, 35 of the 100 elderly female subjects reported at least one fall and were termed *fallers.* Sixteen of these subjects reported two or more falls and were termed *frequent fallers*, and 19 had reported a history of at least one fall in the previous year and were termed *recurrent fallers.* All faller groups reported a greater proportion of falls in the previous year than did nonfallers ($p < .003$; Table 1).

Clinical Balance Tests

To address the first purpose of the study and determine the predictive ability of clinical balance tests, a direct logistic regression model was used. Seven input variables were included: Berg Balance Scale score, anterior reach distance (right and left), lateral distance (right and left), and number

Table 1. Characteristics of Nonfallers and Faller Groups

Characteristic	Proportion[†] Nonfallers (n = 65)	Fallers (n = 35)	Frequent Fallers[‡] (n = 16)	Recurrent Fallers[§] (n = 19)
Mean age (years)	72.3 ± 0.6	74.1 ± 1.1	74.3 ± 1.8	75.1 ± 1.3
Balance confidence (ABC score/100)	87.4 ± 1.3	86.5 ± 2.1	84.7 ± 4.3	81.8 ± 3.4
Mental status (MMSE score/30)	29.2 ± 0.1	28.9 ± 0.2	28.8 ± 0.4	28.8 ± 0.3
Falls history (fallen in past year)	24.6% (16)	54.3% (19)*	56.3% (9)*	100% (19)*
Uses a walking aid (all = cane)	7.7% (5)	5.7% (2)	12.5% (2)	11% (2)
Self-reported medical history				
Dizziness	32.3% (21)	25.7% (9)	18.8% (3)	31.6% (6)
Hearing problems	20.0% (13)	31.4% (11)	31.3% (5)	42.1% (8)*
Reduced sensation	18.5% (12)	20.0% (7)	31.3% (5)	15.8% (2)
Vision problems	20.0% (13)	23.1% (8)	12.5% (2)	26.3% (5)
Prescribed medication: nil	26.2% (17)	25.7% (9)	25.0% (4)	36.8% (7)
1–2/day	43.3% (28)	54.3% (19)	43.8% (7)	52.6% (10)
3–4/day	23.1% (15)	14.3% (5)	25.0% (4)	5.3% (1)
>4/day	7.7% (5)	5.7% (2)	6.3% (1)	5.3% (1)
Self-reported activity level				
Nil exercise	21.5% (14)	17.1% (6)	18.8% (3)	26.3% (5)
Minimal exercise (1–2 h/wk)	50.8% (33)	60.0% (21)	62.5% (10)	52.6% (10)
Moderate exercise (3–4 h/wk)	20.0% (13)	17.1% (6)	12.5% (2)	15.8% (2)
Maximal exercise (>4 h/wk)	7.7% (5)	5.7% (2)	6.3% (1)	5.3% (1)

Notes: ABC = Activities-specific Balance Confidence scale; MMSE = Mini-Mental State Examination.
[†]Percent (number) or mean ± *SD*.
[‡]Frequent fallers: adults who fell more than once in the follow-up period.
[§]Recurrent fallers: adults who fell in the follow-up period who also reported a fall in the previous year.
*$p < .05$.

of steps (right and left). This model did not significantly predict faller status ($p = .762$). Only 12% of fallers and 95% of nonfallers were correctly predicted, with an overall prediction rate of 66% (Table 2). When a sequential logistic regression was performed for each group of variables in order of significance, again none alone were predictive of fallers. No differences between groups were found in any of the balance measures prior to the follow-up period (Table 3).

Differences in Laboratory Measures Between Faller and Nonfaller Groups

Several variables were different between fallers and nonfallers prior to the follow-up period (Table 4). Fallers had a slower step time ($p = .009$) and movement time ($p = .003$) in the step task in a neutral preparation condition. In addition, they had a delayed onset of gluteus medius and hip adductors in both preparation conditions ($p < .007$). There were no between-group differences in either the limits of stability or the quiet-stance measures of COP motion. When nonfallers were compared with frequent fallers and recurrent fallers, a slower movement time was found in both faller groups. Frequent fallers also showed a delay in gluteus medius and tensor fascia latae, whereas recurrent fallers showed a slower step time, total time, and delayed hip adductors.

Prediction of Fallers

The second purpose of the study was to determine the ability of laboratory measures of postural stability to predict fallers. To achieve this, the predictive abilities of all variables were analyzed to determine which best predicted faller status, and the ability of various groups of variables

Table 2. Prediction of Fallers Versus Nonfallers With Logistic Regression Models

Predictor Variables	Model Significance	Sensitivity (% fallers)	Specificity (% nonfallers)	Overall Prediction
Step time (neutral preparation)	0.007	14% (5/35)	94% (61/65)	66%
Eight laboratory measures[†]	0.001	51% (18/35)	91% (59/65)	77%
Step movement speed[‡]	0.001	34% (12/35)	89% (58/65)	70%
EMG onset times[§]	0.142	23% (8/35)	88% (57/65)	65%
COP in quiet stance[‖]	0.150	29% (10/35)	88% (57/65)	67%
COP at LOS[¶]	0.476	6% (2/35)	97% (63/65)	65%
Clinical balance tests[#]	0.762	12% (4/35)	95% (61/65)	66%
Lab + clinical[††]	0.760	59% (20/35)	86% (55/65)	77%

Notes: EMG = electromyogram; COP = center of pressure; LOS = limits of stability.
[†]Included gluteus medius onset time, movement time and step time in a high preparation step task; maximum COP excursion when moving to the right LOS; and COP maximum mediolateral velocity and total distance moved in quiet stance.
[‡]Included the 6 measures: movement time, step time and total time in a high and neutral preparation step task.
[§]Included the 8 measures: gluteus medius, tensor fascia latae, hip adductors and gastrocnemius onset times in a high and neutral preparation step task.
[‖]Included the 6 measures: COP maximum mediolateral velocity, position and total distance moved in quiet stance with eyes open and closed.
[¶]Included the 8 measures: COP maximum excursion when moving to the right LOS, left LOS, anterior LOS and posterior LOS.
[#]Included the 7 measures: Right and left Functional Reach, Lateral Reach, Step-Up number and Berg Balance Scale score.
[††]Included 15 measures: the 8 laboratory measures (see Table body) and the 7 clinical balance tests.

Table 3. Clinical Balance Test Results by Faller Groups

	Nonfallers ($n = 65$)	Fallers ($n = 35$)	Frequent Fallers† ($n = 16$)	Recurrent Fallers‡ ($n = 19$)
Berg Balance Scale (score/56)	53.9 ± 0.6	53.4 ± 0.9	52.3 ± 2.0	52.3 ± 1.7
Functional Reach right (cm)	29.6 ± 0.8	29.1 ± 1.3	29.3 ± 2.2	29.3 ± 1.6
Lateral Reach right (cm)	20.4 ± 0.6	20.1 ± 0.9	18.6 ± 1.2	19.9 ± 1.3
Step-Up Test right (number)	15.6 ± 0.5	14.7 ± 0.8	14.7 ± 1.4	13.9 ± 1.0

†Frequent fallers: adults who fell more than once in the follow-up period.
‡Recurrent fallers: adults who fell in the follow-up period who also reported a fall in the previous year.
*$p < .05$.

was investigated to determine if a combination of variables had a better predictive ability. Using a direct logistic regression model, the best prediction obtained with one variable only was found using the step time (from foot off to contact with the step) in the neutral (uncertain) preparation condition of the step task ($p = .007$; Table 2). However, this only correctly predicted 5 out of 35 fallers (14.3%) and 61 out of 65 nonfallers (93.8%) for a total predictive ability of 66%. The next best predictors were gluteus medius onset time in the high and neutral preparation conditions ($p = .023$ and $p = .032$, respectively), and these also had similarly low sensitivities, predicting only 11.4% and 8.6% of fallers correctly.

To determine whether the possible inclusion of once-only fallers in the faller group may have included subjects without balance problems, the statistics were repeated on frequent fallers and recurrent fallers. The step task movement time (neutral preparation) was again most predictive of frequent fallers and recurrent fallers, but with a better sensitivity. It predicted 5 out of 16 (31.25%) frequent fallers, 4 out of 19 (21%) recurrent fallers, and 61 out of 65 (95.3%) nonfallers in both models.

To determine whether groups of balance measures provided a better prediction of faller status, several models of logistic regression were performed, in both direct and sequential methods of predictor entry. The first investigated variables reflective of some aspect of ML postural stability in each of the three tasks. The variables selected were also found to demonstrate greatest differences between healthy young and older adults in a previous study using the same methodology (30). They included: movement time (in high and neutral preparation conditions), step time (in high and neutral preparation conditions), and gluteus medius onset time (in neutral preparation condition) in the step task; COP total distance and ML velocity in quiet stance with eyes open; and maximum right lateral LOS. This model predicted 18 out of 35 fallers (51%) and 59 out of 65 nonfallers (91%), with an overall success rate of 77% (Table 2).

Step Movement Times

Individual models were then created with all the laboratory measures used as predictor variables to determine if one group of measures was more predictive of fallers. The speed of the performance of the step movement—with the variables movement time, step time, and total time for the high and neutral preparatory conditions—was investigated using a direct model. This significantly predicted faller groups ($p < .001$), with 34% of the fallers and 89% of the nonfallers correctly predicted for an overall success rate of 70% (Table 2). Again, step time reliably predicted faller status ($p < .002$), with trends for movement time (high preparation, $p < .016$) and step time (neutral preparation, $p < .017$). When the same variables were entered in a sequential logistic regression in the order of significance, the same pattern of significance and trends remained.

Muscle Onset Times

Onset times of the proximal hip muscles (right gluteus medius, right tensor fascia latae, and left hip adductors) at high and neutral preparatory levels did not significantly predict faller groups ($p = .142$), despite an overall success rate of 65%, with 23% of the fallers and 88% of the nonfallers correctly predicted (Table 2). No onset time variable reliably predicted faller status individually. The same variables were entered in a sequential logistic regression, with the gluteus medius (neutral preparation) onset time entered first. A significant difference ($p < .006$) between the gluteus medius onset time and the constant was found, predicting 11% of the fallers and 89% of the nonfallers correctly, and an overall success rate of 62%. Sequential entry of all other muscle onsets did not significantly improve prediction success.

COP Measures

COP measures alone did not successfully predict faller status. When limits of stability in each of the four directions were entered into a direct model, they did not significantly differ from the constant only model ($p = .476$), with only 6% of fallers, but 97% of nonfallers correctly predicted, resulting in an overall predictor success rate of 65% (Table 2). Similarly, measures of spontaneous COP motion (ML velocity, position, and total distance) in both visual conditions were not significantly different from a constant-only model ($p = .15$). These measures were able to correctly predict 29% of fallers and 88% of nonfallers. None of the variables in each measurement category were predictive of fallers when entered sequentially.

To test our final hypothesis that clinical measures would improve the prediction obtained with laboratory tests, a sequential logistic regression was applied adding the clinical measures (examined in the previous model) to the eight laboratory measures reflective of ML stability (examined in the first model). Despite an improvement in sensitivity (59%), the overall success rate remained the same (77%) and was not significantly improved from the first model (Table 2).

Discussion

The aim of this study was to determine whether clinical balance tests and laboratory measures reflective of postural stability were able to prospectively predict falls in a com-

Table 4. Difference in Laboratory Measures Between Fallers and Nonfallers

Postural Stability Measure	Nonfallers ($n = 65$)	Fallers ($n = 35$)	Frequent Fallers ($n = 16$)	Recurrent Fallers ($n = 19$)
Step movement speed (ms)				
High preparation				
RT	248 ± 8	237 ± 10	241 ± 15	251 ± 16
WT	509 ± 18	514 ± 24	519 ± 22	517 ± 25
ST	361 ± 17	388 ± 27	371 ± 28	409 ± 37
MT	589 ± 22	666 ± 31	628 ± 29	712 ± 62
TT	1160 ± 33	1237 ± 60	1237 ± 97	1354 ± 103
Neutral preparation				
RT	235 ± 12	244 ±14	239 ± 17	247 ± 18
WT	611 ± 16	621 ± 18	624 ± 16	634 ± 19
ST	317 ± 15	401 ± 33*	381 ± 37	419 ± 46*
MT	552 ± 19	674 ± 38*	643 ± 44*	718 ± 59*
TT	1162 ± 26	1320 ± 43	1320 ± 141	1445 ± 132*
EMG onset times (ms)				
High preparation				
RGM	−68 ± 20	108 ± 22*	24 ± 26*	−11 ± 34
RTFL	−131 ± 24	−46 ± 28*	−16 ± 39*	−78 ± 38
LHA	−100 ± 24	−5 ± 33*	−27 ± 29	21 ± 52*
Neutral preparation				
RGM	−79 ± 21	5 ± 28*	36 ± 35*	−13 ± 41
RTFL	−153 ± 25	−80 ± 32	−57 ± 46	−76 ± 48
LHA	−145 ± 23	−47 ± 37*	−56 ± 34	−29 ± 56*
COP–quiet stance				
Eyes open				
ML position (mm)	3.7 ± 1	−1.1 ± 2	−2.2 ± 4	0.9 ± 3
ML velocity (mm/s)	1.0 ± 0.1	1.1 ± 0.1	1.2 ± 0.2	1.2 ± 0.2
ML amplitude (mm)	2.2 ± 0.1	2.4 ± 0.2	2.8 ± 0.4	2.7 ± 0.3
Total distance (mm)	353 ± 17	380 ± 22	446 ± 58	423 ± 52
Eyes closed				
ML position (mm)	3.4 ± 1	0.3 ± 2	2.3 ± 0.2	2.4 ± 2
ML velocity (mm/s)	1.5 ± 0.1	1.3 ± 0.1	1.3 ± 0.1	1.4 ± 0.2
ML amplitude (mm)	2.7 ± 0.1	2.2 ± 0.2	2.3 ± 0.2	2.2 ± 0.2
Total distance (mm)	498 ± 33	482 ± 30	498 ± 41	481 ± 47
COP–LOS				
Right LOS				
COPmax (%)	55.6 ± 2	60.6 ± 2	61.3 ± 3	61.1 ± 3
Left LOS				
COPmax (%)	56.0 ± 2	60.6 ± 2	63.5 ± 3	57.9 ± 3
Anterior LOS				
COPmax (%)	52.3 ± 2	57.1 ± 2	59.1 ± 4	54.1 ± 4
Posterior LOS				
COPmax (%)	56.2 ± 2	57.0 ± 3	58.4 ± 5	60.3 ± 4

Notes: Values are mean ± *SD*. EMG = electromyogram; COP = center of pressure; LOS = limits of stability; RT = reaction time; WT = weightshift time; ST = step time; MT = movement time; TT = total movement time; RGM = right gluteus medius; RTFL = right tensor fascia latae; LHA = left hip adductor muscle group; ML = mediolateral; ML position = average COP position relative to center of plates (mm); ML velocity = average velocity of COP displacement (mm/s); ML amplitude = root-mean-square COP displacement (mm); Total distance = total COP displacement (mm); COP max = peak COP position as a percentage of foot length or width (%).

*$p < .01$.

munity-dwelling elderly population over a 6-month period. The early detection of elderly adults with potential for falling may allow timely referral to an appropriate fall prevention program.

Clinical Balance Tests Prediction

The first purpose of this study was to determine the predictive ability of clinical balance tests. We unexpectedly found no differences in clinical balance test performance between fallers and nonfallers, and no tests significantly predicted faller status. This differs from several previous studies that found similar clinical tests to be predictive of fallers (9,10,12). The inability of the clinical tests to predict fallers, or to distinguish between fallers and nonfallers in the current study, may be due to several factors. First, the population studied was made up of relatively healthy, independent, community-dwelling older women, who appear to have been functioning at a higher level than subjects in other studies. Any changes in balance may have been subtle and not able to be detected by the clinical tests. The clinical tests did not include elements of reactive control and the Berg Balance Scale had a ceiling effect for higher functioning persons.

A second difference was that this study examined subjects prior to a fall and not retrospectively. The balance ability of older adults after a fall is likely to be reduced due to factors such as injury and fear, and thus differences between fallers and nonfallers may be more evident with a retrospective design (9). Finally, as discussed later, the grouping of subjects into faller and nonfaller groups is critical to ensuring accurate prediction. Despite rigorous follow-up procedures, the 6-month follow-up period may not have been sufficient to allow for the occurrence of a fall. Thus, it appears that, for this population, the clinical tests used were not able to prospectively detect falling risk.

Laboratory Measures

In addressing the second purpose of the study to investigate laboratory measures, differences were found between fallers and nonfallers in variables associated with the reaction-time step task. Fallers were significantly slower in their step and movement times, but not in their reaction time or weightshift time. They also demonstrated a delay in gluteus medius, a proximal muscle associated with ML control (31). These findings indicate a difference in the ability to activate a muscle with a primary role in weight transference and a slowing of a lower limb movement. This supports previous studies that noted that elderly subjects with larger delays in postural muscle onset were less stable when performing a rapid limb movement task (32,33). Several studies have also indicated that a reduction in control of the body in the ML direction in quiet stance (16) and during gait initiation (34) is associated with elderly fallers. The ability to generate stabilizing postural responses to maintain ML postural stability may be important in preventative intervention targeting elderly potential fallers. The fact that similar differences and trends were also found in frequent and recurrent fallers strengthens this finding.

Sensitivity and Specificity of Laboratory Measures

The laboratory variables studied here were better able to predict nonfallers than fallers. These results are similar to Bogle-Thorbahn (10), but differ from several other predictive studies (9,16). The subjects who performed well on the balance tests and measures were not likely to fall, whereas those who performed poorly did not necessarily fall. This lack of specificity may be caused by several factors.

First, the follow-up period was only 6 months. Those who performed poorly on balance tests may have fallen (and specificity improved) if the follow-up period had been longer. Despite this, the proportion of fallers detected in the current study (35%) is similar to that previously reported by other authors over a 1-year time period (1–3). One of the primary reasons for the high falls detection rate in this study is likely to be the rigorous follow-up procedure used in the current study. Poor recall of events is a common confounder encountered by researchers investigating falls (35). In this study, daily recording and regular telephone calls from the investigator ensured a high proportion of falls were recalled and thus reported. Thus, falls may have been recorded and people classified as fallers who may have been missed in previous studies. Conversely, it is possible that some subjects who actually fell did not report a fall and were subsequently misclassified. The classification of subjects is a crucial aspect to predictive studies. The small numbers of subjects reporting only one type of fall (e.g., COM-only falls) precluded the analysis of data by fall type, which could yield further information regarding the nature of the postural instability.

A second reason for subjects with poor balance to have not fallen was that they may not have placed themselves in a risky situation. Examination of functional ability and risk-taking behavior is required to ascertain if this was an issue. Third, the subjects were relatively independent community-dwelling older adults and, as mentioned in relation to clinical tests, the measures may not have been sensitive enough to detect changes. Fourth, there is a possibility that, despite reporting predominantly biomechanically related falls, fallers may not have had a reduction in balance ability that was detectable by these measures. The falls could have been caused by factors other than poor balance alone.

The best prediction of elderly fallers from postural stability measures alone (77%) resulted from preselected combination variables from laboratory measure, all with some relation to ML postural stability. No individual measurement (e.g., quiet-stance COP measures) provided a better prediction of fallers. This result illustrates the multifaceted nature of the decline in balance ability associated with elderly persons who fall and suggests that a comprehensive assessment of balance function is optimal, rather than performing only one type of measurement or task. Unlike Maki (16), this study did not find any spontaneous COP measures to be predictive of fallers. One reason for this difference may be attributed to the population studied. Although both studies investigated community-dwelling older adults, the subjects in Maki's (16) study were older (mean age 83 $\pm$ 3 years vs 74 $\pm$ 6 years) and appeared to be more frail than those in the current study. Twenty-two percent of the fallers in Maki's (16) study always used a walking aid, as opposed to 6% in the current study. A final difference in the studies was the follow-up period and procedure, which may have resulted in a slightly different subject grouping.

Although the hypothesis that the addition of clinical balance tests to the laboratory measures would significantly improve the prediction of fallers was not accepted, the sensitivity of the model improved. One major reason for this was the relatively high level of balance ability in the subjects in this study. Although the Berg Balance Scale has previously been shown to predict fallers (10), the high scores of fallers in this study on all clinical tests suggest that the tests investigated here have limited predictive abilities when assessing this population of community-dwelling older adults.

The fact that the balance measures were unable to predict all fallers suggests that balance is not the only risk factor important in this group of active, community-dwelling fallers. However, measures of postural stability reflective of ML postural control were different between fallers and nonfallers and were able to predict most nonfallers and some fallers. These results support the development of clinical balance tests more sensitive to subtle changes in postural stability. Development of these tests is important to the early detection and prevention of falls in the more independent elderly population.

Acknowledgments

This research was supported by the Public Health Research and Development Committee (Grant 96/4141) from the National Health and Medical

Research Council (Australia). Dr. Brauer was supported by the Menzies' Foundation Research Scholarship for the Allied Health Sciences.

Address correspondence to Dr. Sandra Brauer, Department of Exercise and Movement Science, University of Oregon, Eugene, OR 97403-1240. E-mail: sbrauer@uoneuro.uoregon.edu

References

1. Campbell AJ, Borrie MJ, Spears GF. Risk factors for falls in a community-based prospective study of people 70 years and older. *J Gerontol Med Sci*. 1989;44:M112–M117.
2. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. *N Engl J Med.* 1988;319:1701–1707.
3. Lach HW, Reed AT, Arfken CL, et al. Falls in the elderly: reliability of a classification system. *J Am Geriatr Soc.* 1991;39:197–202.
4. Wild D, Nayak USL, Isaacs B. Characteristics of old people who fell at home. *J Clin Exp Gerontol.* 1980;2:271–287.
5. Campbell JA, Borrie MJ, Spears GF, Jackson SL, Brown JS, Fitzgerald JL. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. *Age Aging.* 1990;19:136–141.
6. Lord S, Ward J, Williams P, Anstey K. An epidemiological study of falls in older community dwelling older women: the Randwick falls and fracture study. *Aust J Pub Health.* 1993;17:240–245.
7. Bhala RP, O'Donnell J, Thoppil E. Ptophobia: phobic fear of falling and its clinical management. *Phys Ther.* 1982;62:187.
8. Tinetti ME, Leon C, Doucette JT, Baker DI. Fear of falling and fall related efficacy in relationship to functioning among community-living elders. *J Gerontol Med Sci.* 1994;49:M140–M147.
9. Shumway-Cook A, Baldwin M, Polissar NL, Gruber W. Predicting the probability for falls in community-dwelling older adults. *Phys Ther.* 1997;77:812–819.
10. Bogle-Thorbahn L, Newton R. Use of the Berg Balance Test to predict falls in elderly persons. *Phys Ther*. 1996;76:576–585.
11. Thapa PB, Gideon P, Brockman KG, Fought RL, Ray WA. Clinical and biomechanical measures of balance as fall predictors in ambulatory nursing home residents. *J Gerontol Med Sci.* 1996;51A:M239–M246.
12. Duncan PW, Studenski S, Chandler J, Prescott B. Functional reach: predictive validity in a sample of elderly male veterans. *J Gerontol Med Sci*. 1992;47:M93–M98.
13. O'Loughlin JL, Robitaille Y, Boivin JF, Boivin JF, Suissa S. Incidence of and risk factors for falls and injurious among the community dwelling elderly. *Am J Epidemiol*. 1993;137:342–354.
14. Studenski S, Duncan PW, Chandler J, et al. Predicting falls: the role of mobility and nonphysical factors. *J Am Geriatr Soc.* 1994;42:297–302.
15. Lord SR, Clarke RD, Webster IW. Postural stability and associated physiological factors in a population of aged persons. *J Gerontol Med Sci.* 1993;46:M69–M76.
16. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *J Gerontol Med Sci*. 1994;49:M72–M84.
17. Bartlett SA, Holliday PJ, Maki BE. On the classification of a geriatric subjects as a faller or non-faller. *Med Biol Eng Comput*. 1986;24:219.
18. Folstein MF, Folstein SE, McHugh PR. "Mini-Mental State": a practical method for grading the cognitive state of patients for the clinician. *J Psychiat Res.* 1975;12:189–198.
19. Powell LE, Myers AM. The activities-specific balance confidence (ABC) scale. *J Gerontol Med Sci*. 1995;50A:M28–M34.
20. Berg K, Wood-Dauphinee S, Williams JI, Gayton D. Measuring balance in the elderly: preliminary development of an instrument. *Physiother Can.* 1989;41:304–311.
21. Duncan P, Studenski S, Chandler J, Prescott B. Functional reach: a new clinical measure of balance. *J Gerontol Med Sci*. 1990;45:M192–M197.
22. Brauer S, Burns Y, Galley P. Lateral Reach: A clinical measure of medio-lateral postural stability. *Physiother Res Int*. 1999;4:81–88.
23. Hill K, Bernhardt J, McGann A, Maltese D, Berkovits D. A new test of dynamic standing balance for stroke patients: reliability, validity and comparison with healthy elderly. *Physiother Can*. 1996;Fall:257–263.
24. Tinetti ME, Williams TF, Mayewski R. Fall risk index for elderly patients based on number of chronic disabilities. *Am J Med.* 1986;80: 429–434.
25. Podsiadlo D, Richardson S. The timed up and go: a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc.* 1991;39: 142–148.
26. Piotrowski A, Cole J. Clinical measures of balance and functional assessment in elderly persons. *Aust J Physiother.* 1994;40:183–188.
27. Berg KO, Maki BE, Williams JI, Holliday PJ, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. *Arch Phys Med Rehabil*. 1992;73:1073–1080.
28. Hageman PA, Leibowitz JM, Blanke D. Age and gender effects on postural control measures. *Arch Phys Med Rehabil.* 1995;76:961–965.
29. Topper AK, Maki BE, Holliday PJ. Are activity-based assessments of balance and gait predictive of risk of falling and/or type of fall? *J Am Geriatr Soc.* 1993;41:479–487.
30. Brauer S. *Medio-lateral Postural Stability: Changes With Age and in Fallers*. Unpublished doctoral thesis. University of Queensland, Australia;1998.
31. Rogers MW, Pai Y. Pattern of muscle activation accompanying transitions in stance during rapid leg flexion. *Electromyog Kinesiol.* 1993;3: 149–156.
32. Man'kovskii N, Mints YA, Lysenyuk UP. Regulation of the preparatory period for complex voluntary movement in old and extremely old age. *Hum Physiol.* 1980;6:46–50.
33. Woollacott M, Manchester D. Anticipatory postural adjustments in older adults: are changes in response characteristics due to changes in strategy? *J Gerontol Med Sci*. 1993;48:M64–M70.
34. Chang H, Krebs DE. Dynamic balance control in elders: gait initiation assessment as a screening tool. *Arch Phys Med Rehabil.* 1999;80:490–494.
35. Cummings SR, Nevitt MC, Kidd S. Forgetting falls: the limited accuracy of recall of falls in the elderly. *J Am Geriatr Soc.* 1988;36:613–616.

Received July 7, 1999
Accepted December 29, 1999
Decision Editor: John E. Morley, MB, BCh