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Lateral Balance Factors Predict Future Falls in Community-Living Older Adults

Marjorie Johnson Hilliard, PT, MS, **Katherine M. Martinez, PT, MA**, **Imke Janssen, PhD**, **Beatrice Edwards, MD**, **Marie-Laure Mille, PhD**, **Yunhui Zhang, MS**, and **Mark W. Rogers, PhD, PT**

Departments of Physical Therapy and Human Movement Sciences (Hilliard, Martinez, Mille, Zhang, Rogers), Physical Medicine and Rehabilitation (Rogers), and Medicine (Edwards), Feinberg School of Medicine, Northwestern University, Chicago, IL; and Department of Preventive Medicine, Rush University Medical School, Chicago, IL (Janssen)

Abstract

Objective—To prospectively determine the capacity of measures of mediolateral (ML) protective stepping performance, maximum hip abduction torque, and trunk mobility, in order to predict the risk of falls among community-living older people.

Design—Cross-sectional study.

Setting—A balance and falls research laboratory.

Participants—Medically screened and functionally independent community-living older adult volunteers (N=51).

Interventions—Not applicable.

Main Outcome Measures—Measures included: (1) protective stepping responses: percentage of trials with multiple balance recovery steps and sidestep/crossover step recovery patterns, and first step length following motor-driven waist-pull perturbations of ML standing balance; (2) hip abduction strength and axial mobility: (3) peak isokinetic hip abduction joint torque and trunk functional axial rotation (FAR) range of motion; and (4) fall incidence: monthly mail-in reporting of fall occurrences with follow-up contact for 1 year post-testing. One- and 2-variable logistic regression analysis models determined which single and combined measures optimally predicted fall status.

Results—The single variable model with the strongest predictive value for falls was the use of multiple steps in all trials (100% multiple steps) (odds ratio, 6.2; *P*=.005). Two-variable models, including 100% multiple steps and either hip abduction torque or FAR variables, significantly improved fall prediction over 100% multiple steps alone. The hip abduction and FAR logistic regression optimally predicted fall status.

Conclusions—The findings identify new predictor variables for risk of falling that underscore the importance of dynamic balance recovery performance through ML stepping in relation to neuromusculoskeletal factors contributing to lateral balance stability. The results also highlight focused risk factors for falling that are amenable to clinical interventions for enhancing lateral balance function and preventing falls.

Reprint requests to Mark W. Rogers, PhD, PT, Dept of Physical Therapy and Human Movement Sciences, Northwestern University Medical School, 645 N Michigan Ave, Ste 1100, Chicago, IL 60611, mrogers@som.umaryland.edu.

Suppliers

Keywords

Accidental falls; Aging; Rehabilitation

With advancing age, the tendency to experience falls increases rapidly. Numerous risk factors for falling have been identified, and have served as focal points for clinical interventions aimed at reducing the risk of falls.[1–5] Among these factors, aging limitations in postural balance and gait functions have been consistently linked with falls.[5] Therefore, various laboratory and clinical tests of balance and gait have been used in attempts to predict the risk of falling.[2,4]

Although the majority of prior falls prediction studies have focused on balance and gait performance involving the AP plane of motion, there is accumulating evidence that aging effects on balance may be accentuated in the ML direction. For example, in community-dwelling older adults, measures of ML postural sway have been associated with past falls,[1] future risk of falls,[2] and recurrent falls.[3] However, another report found that more dynamic tests such as rapid voluntary stepping, which challenges aspects of ML stability, provided a better prediction of falls.[4] Because most falls occur during dynamic activities (eg, collisions, slips, trips),[5] the latter finding highlights the importance of evaluating relationships between dynamic balance abilities and fall risk.

Aging limitations in lateral balance recovery through stepping are particularly relevant to the risk of falling. During imbalance, stepping represents a commonly executed protective option that may precede grabbing nearby objects to prevent falling, or rapidly extending the arms to absorb the impact of a fall. Following external challenges to ML standing balance, older people use more steps and arm reactions to recover their balance than younger adults.[6,7] Aging changes in ML stepping also include frequent collisions between the limbs[6,7] with altered first step characteristics and postural movements of the trunk.[7] These observations emphasize that older people may be particularly vulnerable to lateral instability that might increase their risk of falling.[8] However, the link between lateral protective stepping ability and future risk of falling is currently unknown.

From a biomechanics standpoint, the control of lateral balance stability while standing stationary and during stepping is normally dependent on hip joint abductor-adductor torque production and postural movements of the trunk.[7,8] Aging impairments in these segmental neuromusculoskeletal factors could contribute to lateral instability.[9,10] In combination with key measures of ML stepping performance, identification of neuromusculoskeletal impairments affecting postural balance in older adults could identify treatable risk factors associated with falls.

The objectives of this study were: (1) to prospectively determine the capacity of preselected measures of ML protective stepping performance, maximum hip abductor torque, and trunk mobility to predict falls among older community-dwelling subjects; and (2) to compare which combinations of ML protective stepping measurements and segmental neuromusculoskeletal factors provide the best prediction of future falls.

METHODS

Participants

Fifty-one community-dwelling adults with a mean age of 73.3±6.3 years (range, 62–86y) participated in this study. Seventy-five percent of subjects were women (n=38). Subjects were recruited through an aging research registry and geriatric evaluation service. An initial telephone screening excluded subjects who used an assistive device to ambulate indoors, had been hospitalized within the last 6 months, had a history of any central nervous system disorders or general medical or musculoskeletal problems that limited functional activities, or had undergone orthopedic surgery to the hips, knees, or ankles such as joint replacements. Additional exclusion criteria included any current injuries, significant foot deformities, or uncorrected vision or hearing difficulties that limited activities of daily living or communication. A board-certified physician geriatrician evaluated medical history, vital signs, vision, hearing, musculoskeletal and neurologic systems, and cognitive function through the Folstein Mini-Mental State Examination (minimum inclusion score, 23/30). All subjects signed an informed consent form approved by the institutional review board prior to their participation.

Protective Stepping Assessment

We applied postural perturbations in the right lateral and left lateral directions by position-controlled, motor-driven waist-pulls[11] of constant magnitude (amplitude, 22.5cm; velocity, 31.5cm/s; acceleration, 900cm/s^2) that always induced steps. The details of the perturbation method have been presented previously[7,8,11] and are briefly summarized here. Motor control is accomplished through an imbedded controller and digital encoder. The system can selectively perturb balance in 1 of 6 possible directions by combining the functions of a pulley-cable and switching system. The pulley-cable system contains up to 6 pulling cables and moveable pulleys mounted on height adjustable vertical posts. A first post aligned with the motor redirects 2 sets of 3 pulling cables on each side of the recording area. The 6 other vertical posts are positioned symmetrically on both sides of this area and are oriented at an angle of 30° to each other. A position transducer (linear variable differential transformer) located on the drive table records pulling motion and in-line load cells at the interfaces of the cables and belt record pulling force.

For each trial, subjects placed each foot on a separate force platform[a] that recorded the ground reaction forces at a sampling frequency of 500Hz. Body segment kinematics were recorded for 5 seconds at a sampling rate of 60Hz using a 6-camera motion analysis system[b] that captured the motion of reflective markers placed over 17 bony landmarks. Step characteristics were measured as described in a previous study.[7] An adjustable waist-belt was snugly secured and imbedded connector clasps aligned with each greater trochanter where the pulling cables were attached. Although our focus was on responses to directly lateral pulls, cables were also attached to the waist-belt in 4 other perturbation directions (30° forward and backward left and right) to further minimize subject certainty about the pull direction. Subjects wore a safety harness and received 5 perturbation trials for each pull direction in the same pseudorandom order. They were instructed to “react naturally to prevent themselves from falling” in response to the perturbation.

The numbers of steps were documented by observation and kinematics. Responses were categorized as 100% multiple steps if they included more than 1 step in every trial. This dichotomous variable provides a simple yes/no clinical marker of stepping performance. Two main ML stepping strategies have been previously observed[7]: (1) a loaded side step with the passively loaded leg (near side to pull); and (2) an unloaded crossover step, either in front of or behind the body, with the passively unloaded leg (far side to pull). The percentages of trials with unloaded crossover steps and with loaded side steps were calculated. Stepping motion characteristics were determined using customized analysis programs.[7] The beginning and end of the first step was identified from the vertical velocity of the step side ankle marker in order to determine the combined ML and AP first step displacement, reflecting global step length.

[a]Advanced Mechanical Technology Inc, 176 Waltham St, Watertown, MA 02472.
[b]Motus; Vicon, 7388 S Revere Pkwy, Ste 901, Centennial, CO 80112.

Isokinetic Hip Abduction Torque

A calibrated Biodex System 3 PRO dynamometer[c] measured isometric and isokinetic (60°/s) hip abduction joint torques of the dominant leg. The participants were tested in standing with a custom designed body stabilization frame using methods described previously.[9]

Functional Axial Rotation Measurement

We measured trunk mobility using the FAR protocol, which assesses global axial motion of the trunk, head, and neck.[12] Following standardized procedures, the seated subject was instructed to turn as far as possible to the right and then to the left without lifting the buttocks from the support surfaces. The degree of motion was determined using a pointer attached to a head band and was quantified by recording the alignment of the pointer with calibrated lines located 5° apart on the inside surface of a circular band (FAR physical variable), and by asking subjects to report the farthest line that they could see (FAR visual variable).

Prospective Falls Assessment

We followed the fall history of each subject prospectively for a period of 1 year after laboratory testing. A fall was defined as "an event, which results in a person coming to rest inadvertently on the ground or other lower level regardless of whether an injury was sustained, and not as a result of a major intrinsic event or overwhelming hazard."[1,13] An overwhelming hazard was defined as "a hazard that would result in a fall by most young, healthy persons"[13] as determined by a consensus of at least three of the investigators. For example, a fall due to orthostatic hypotension would be considered a major intrinsic event, whereas a fall resulting from walking on an unlevel, ice covered surface would be considered an overwhelming hazard.

On a monthly basis, subjects reported whether they experienced any falls by completing a postage-paid, preaddressed postcard. Follow-up telephone calls were made to subjects for whom a report was not received within a 2-month time frame, or to determine the circumstances of a reported fall. The prospective monitoring of falls using monthly mail-in reporting with follow-up contact is among the most rigorous approaches.[14]

Statistical Analysis

Descriptive statistics consisted of group means and distributions for each of the measurements. Differences in means between fallers and nonfallers were analyzed using the 2-sample *t* test or, in case of variables with a skewed distribution, the nonparametric Kruskal-Wallis test (100% multiple steps, percentage of crossover steps).

Logistic regression analyses identified potential predictors of a fall. Fall status was included as the dependent variable after dichotomization (0 = nonfaller, no falls in 12-mo prospective follow-up; 1 = faller, ≥1 falls). Potential explanatory variables were selected based on our hypotheses of fall risk factors from the literature and our previous work.[7–9] The following variables were selected as potential predictors: 100% multiple steps, percentage of crossover steps, first global step length (combined ML and AP displacements), functional axial rotation (FAR physical, FAR visual), and peak isokinetic hip abductor torque. First, univariate logistic regression was carried out. Second, a 2-variable logistic regression tested which combination of risk factors best predicted falls. Confidence intervals at 95% were calculated for the odds ratio. A significance level of *P* equal to or less than .05 was used for all tests.

[c]Biodex Medical, 20 Ramsey Rd, Shirley, NY 11967.

RESULTS

Incidence of Falls

An excellent response rate was achieved in the 12-month prospective monitoring of falls with all 51 subjects completing their fall records. Thirty-two (62.7%) of the 51 participants reported having no falls in the follow-up year, and 19 subjects (37.3%) reported 1 or more falls. There were 26 falls overall with 14 subjects falling once, 3 falling twice, and 2 falling 3 times or more. The mean age of the fallers (4 men, 15 women) was 74.8±7.3 years as compared with the nonfallers (9 men, 23 women) mean age of 72.4±5.6 years (*t* test, *P*=.229).

Protective Stepping, Hip Strength, and Trunk Mobility

Table 1 shows that the fallers performed significantly different than the nonfallers for all variables except percentage of crossover steps. Fallers used a greater percentage of multiple steps to recover their balance than the nonfallers (Kruskal-Wallis test, *P*=.018). Fourteen (74%) of 19 fallers used multiple steps in 100% of the trials whereas 10 (31%) of 32 nonfallers used multiple steps in 100% of the trials (χ^2 test, *P*=.003). Fallers showed less trunk mobility as indicated by their lower FAR physical (*t* test, *P*=.006) and FAR visual (*t* test, *P*=.008) scores, executed steps with smaller global step length (*t* test, *P*=.003), and generated lower peak isokinetic hip abductor torque (*t* test, *P*=.008).

Variables Predicting Falls

A logistic regression analysis determined the variables that predicted the probability of falling, excluding percentage of crossover steps due to too little variation in the scores between groups. The maximum number of independent variables in the models tested was limited to 2, with 19 fallers in the smaller group.[15]

Single variable models—Table 2 shows that 5 measures were significant predictors of fall events: 100% multiple step use, global step length, FAR physical, FAR visual, and peak isokinetic hip abductor torque. The single variable with the strongest predictive value was 100% multiple step use. Subjects who used multiple steps to recover their balance 100% of the time were 6.2 times more likely to fall than people who did not always use multiple steps. Single variable analysis also showed that for every decrease of: (1) 30° in FAR physical or FAR visual trunk mobility the odds of falling increased 2.2 times; (2) 10cm in global step length the odds of falling increased 2 times; and (3) 0.1 standardized units of peak isokinetic hip abductor torque normalized by body weight (in $\mathrm{Nm \cdot kg^{-1} \cdot m^{-1}}$) the odds of falling increased 1.8 times.

Two-variable models—The percentage of trials with multiple steps, dichotomized into use of 100% multiple steps or not, was first entered into the model, and then combined with either FAR physical or peak isokinetic hip abductor torque. Using the likelihood ratio test, which compared the single variable 100% multiple steps model with each of the above 2-variable models, both the 100% multiple steps FAR physical model and 100% multiple steps peak isokinetic hip abductor model were significantly better in predicting fall status compared with the 100% multiple step model alone (*P*=.007, *P*=.016, respectively).

The 2-variable model involving continuous variables, FAR physical peak isokinetic hip abductor had a larger log-likelihood than the other 2-variable models. Adding 100% multiple steps to the model containing FAR physical peak isokinetic hip abductor only marginally improved the model with the 2 continuous variables (*P*=.052).

Because based on sample size we are limited to a 2-variable model, the function of the best fitting FAR physical isokinetic hip abductor model is:

$$\text{logit}\ (p)=8.52-.807\times(\text{FAR physical}/30)-.5894\times(\text{peak isokinetic hip abductor torque}\times10)$$

where p is the probability that a person will fall in the next year and FAR physical is functional axial rotation trunk mobility.

One can insert the observed values in the equation, find the estimate of logit (p), and determine the future probability of falling (p) by calculating:

$$p\ \text{falling}=e^{\text{logit}\ (p)}/1+e^{\text{logit}\ (p)}$$

where e is the base of the natural logarithm.

For example, in our study, a 79-year-old woman with 180° of FAR physical trunk axial rotation and .36 peak isokinetic hip abductor torque (normalized by body weight) would have a predicted probability of falling in the next year of 82.4%. In contrast, a 75-year-old woman with 258° of FAR physical trunk axial rotation and .67 peak isokinetic hip abductor would only have a probability of falling in the next year of 8.7%.

Because 100% multiple steps use, FAR physical, peak isokinetic hip abductor torque, and the FAR physical isokinetic hip abductor combined models represented significant predictors of prospective falls, we determined the cutoff scores that provided the highest combination of sensitivity and specificity for predicting 1 or more falls (table 3). For example, in the protective stepping assessment, a cutoff score of 100% multiple steps resulted in 70.5% of the subjects being correctly identified as fallers or nonfallers, a sensitivity of 74%, and a specificity of 69%. For the FAR physical isokinetic hip abductor model we determined a cutoff score of greater than 40% provided the best combination of sensitivity and specificity for predicting fall history. A cutoff score of greater than 40% resulted in 74% of the subjects being correctly identified as fallers or nonfallers, with a sensitivity of 68%, and specificity of 77%.

DISCUSSION

This study showed that laboratory tests of ML stepping performance and associated neuromusculoskeletal factors were significant predictors of the prospective falls among community-living older people. The findings also showed that any 2-variable models combining the use of 100% multiple steps, FAR physical axial rotation, and peak isokinetic hip abductor torque improved prediction of fall risk compared with the most optimal single variable model, 100% multiple steps.

The incidence of falls involving 37% of our subjects generally resembled past studies.[13,14,16,17] Although we did not identify whether the falls among our study sample might have included a laterally oriented fall circumstance, falls to the side are frequent occurrences that significantly increase the risk of hip fracture.[16,18,19] Therefore, postural balance assessments and fall risk determination should explicitly take into account the heightened potential for older people to have impairments of lateral balance function that may increase their risk of falling.

The results pertaining to protective sidestepping are, to our knowledge, among the first to show differences in dynamic balance recovery through stepping in the frontal plane between older adults who subsequently did or did not experience falls. Compared with nonfallers, older fallers took more steps to recover their balance and had a shorter combined forward ML first step length. Multiple recovery steps have been previously found to distinguish older nonfallers from younger adults when balance was perturbed in either the sagittal or frontal planes.[6,7,20] The present findings extend these past observations by showing that older people who subsequently experienced falls executed multiple stepping behaviors to an even greater extent than older nonfallers. Specifically, 74% of the faller group used multiple recovery steps in all trials compared with only 31% of nonfallers. Likewise, the results indicating shorter first step length, primarily during crossover stepping, represent an additional novel finding that further distinguished between the faller and nonfaller groups. These differences shown by the fallers suggested difficulties with controlling stepping movements to relocate the BOS and stabilize the body COM. Because lateral instability, or loss of balance in the frontal plane, occurs when the motion characteristics of the COM with respect to the BOS exceed certain spatiotemporal stability limits,[8] an impaired ability to control lateral balance through stepping is particularly relevant to the problem of falling among older people. It is conceivable that the increased number of recovery steps used by the fallers was, at least in part, related to the shorter first step length, which may have inadequately arrested the body momentum and required additional steps.

Aging changes in skeletal muscle function and decreased joint flexibility are frequently observed neuromusculoskeletal risk factors for falls[8,21–23] that can limit the capacity to produce joint moments of force (torques). The concomitant decreases in trunk mobility and hip abductor joint torque among the faller group could have contributed to the differences in ML stepping performance due to their contributions to frontal plane balance stability.[8,24,25] For example, hip abductor-adductor joint torques are normally involved with regulating ML postural sway,[26] controlling lateral weight transfer,[27] stabilizing the pelvis-trunk segments while walking,[28] and producing limb-movement trajectories during sidestepping.[7] In addition, both lateral and transverse rotational mobility of the axial segments are important elements underlying ML postural movements of the upper-body mass that may be altered with age during protective sidestepping.[7,8] Transverse rotation about the longitudinal axis of the body, which is a principal contributor to the FAR measurement, is particularly relevant to the torsion that accompanies the crossover stepping strategy used especially by older adults.[7]

Both the individual and combined stepping variables and the clinical tests predicted fallers and nonfallers with broadly equivalent sensitivity, specificity, and predictive values. However, 2-variable models combining stepping and neuromusculoskeletal variables improved prediction of fall risk above the most optimal single variable model, 100% multiple step use. Overall, these measures correctly identified about 70% of fallers and nonfallers with predictive values of between 60% and 80%. The results equaled or exceed values reported in other fall prediction studies combining laboratory and clinical balance tests that incorporated dynamic tasks that challenge lateral stability.[2–4,29] In particular, the use of multiple steps for ML balance recovery is a comparatively robust performance variable for identifying future risk of falls.

The assessment of lateral balance factors is useful not only for identifying fall risk, but also for specifying target areas for clinical interventions to prevent falls. From the broader perspective of applying interventions to increase muscular strength, improve balance, and enhance mobility to prevent falls,[5,30,31] therapeutic programs can be tailored to emphasize protective step training in the frontal plane in combination with hip abductor-adductor muscle training and trunk mobility exercises. From a practical standpoint, clinical emphasis on protective stepping need not require sophisticated laboratory perturbation devices such as the waist-pull system used in this study. For example, inducing protective stepping can be effectively accomplished through manual pulls on a cable and harness attachment,[32] by suddenly accelerating a treadmill,[33] or through the use of a padded wand to apply a thrust force to the trunk or pelvis.[25]

Study Limitations

Among the limitations of the study is the preselection of predictor variables based on theoretical grounds and our previous studies. This procedure may have precluded the selection of other possible predictor variables for prospective falls. Restrictions in the subject sample size for fallers limited the multiple regression models to 2 predictor variables. Thus, we were unable to determine whether a larger multivariate regression model would have provided better estimates of prospective falls.

CONCLUSIONS

The findings identify new predictor variables for risk of falling that underscore the importance of dynamic balance recovery performance through ML stepping in relation to neuromusculoskeletal factors contributing to lateral balance stability. The results also highlight focused risk factors for falling that are amenable to clinical interventions for enhancing lateral balance function and preventing falls.

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List of Abbreviations

AP	anteroposterior
BOS	base of support
COM	center of mass
FAR	functional axial rotation
ML	mediolateral

References

1. Lord SR, Rogers MW, Howland A, Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. J Am Geriatr Soc 1999;47:1077–81. [PubMed: 10484249]
2. 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 1994;49:M72–84. [PubMed: 8126355]
3. Stel VS, Smit JH, Pluijm SM, Lips P. Balance and mobility performance as treatable risk factors for recurrent falling in older persons. J Clin Epidemiol 2003;56:659–68. [PubMed: 12921935]
4. Brauer SG, Burns YR, Galley P. A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. J Gerontol A Biol Sci Med Sci 2000;55:M469–76. [PubMed: 10952371]
5. Lord, SR.; Sherrington, C.; Menz, HB. Falls in older people: risk factors and strategies for prevention. Cambridge: Cambridge Univ Pr; 2001.
6. Maki BE, Edmondstone MA, McIlroy WE. Age-related differences in laterally directed compensatory stepping behavior. J Gerontol A Biol Sci Med Sci 2000;55:M270–7. [PubMed: 10819317]
7. Mille ML, Johnson ME, Martinez KM, Rogers MW. Age-dependent differences in lateral balance recovery through protective stepping. Clin Biomech (Bristol, Avon) 2005;20:607–16.
8. Rogers MW, Mille ML. Lateral stability and falls in older people. Exerc Sport Sci Rev 2003;31:182–7. [PubMed: 14571957]

9. Johnson ME, Mille ML, Martinez KM, Crombie G, Rogers MW. Age-related changes in hip abductor and adductor joint torques. Arch Phys Med Rehabil 2004;85:593–7. [PubMed: 15083435]
10. Chang SH, Mercer VS, Giuliani CA, Sloane PD. Relationship between hip abductor rate of force development and mediolateral stability in older adults. Arch Phys Med Rehabil 2005;86:1843–50. [PubMed: 16181952]
11. Pidcoe PE, Rogers MW. A closed-loop stepper motor waist-pull system for inducing protective stepping in humans. J Biomech 1998;31:377–81. [PubMed: 9672092]
12. Schenkman M, Hughes MA, Bowden MG, Studenski SA. A clinical tool for measuring functional axial rotation. Phys Ther 1995;75:151–6. [PubMed: 7846135]
13. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988;319:1701–7. [PubMed: 3205267]
14. Lord SR, Tiedemann A, Chapman K, Munro B, Murray SM, Sherrington C. The effect of an individualized fall prevention program on fall risk and falls in older people: a randomized, controlled trial. J Am Geriatr Soc 2005;53:1296–304. [PubMed: 16078954]
15. Harrell, FE. Regression modeling strategies with applications to linear models, logistic regression and survival analysis. New York: Springer; 2001.
16. Cumming RG, Klineberg RJ. Fall frequency and characteristics and the risk of hip fractures. J Am Geriatr Soc 1994;42:774–8. [PubMed: 8014355]
17. Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. Arch Phys Med Rehabil 2001;82:1050–6. [PubMed: 11494184]
18. Hayes WC, Myers ER, Morris JN, Gerhart TN, Yett HS, Lipsitz LA. Impact near the hip dominates fracture risk in elderly nursing home residents who fall. Calcif Tissue Int 1993;52:192–8. [PubMed: 8481831]
19. Greenspan SL, Myers ER, Maitland LA, Resnick NM, Hayes WC. Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. JAMA 1994;271:128–33. [PubMed: 8264067]
20. Luchies CW, Alexander NB, Schultz AB, Ashton-Miller JA. Stepping responses of young and old adults to postural disturbances: kinematics. J Am Geriatr Soc 1994;42:506–12. [PubMed: 8176145]
21. Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. N Engl J Med 1995;332:556–61. [PubMed: 7838189]
22. Kerrigan DC, Todd MK, Della Croce U, Lipsitz LA, Collins JJ. Biomechanical gait alterations independent of speed in the healthy elderly: evidence for specific limiting impairments. Arch Phys Med Rehabil 1998;79:317–22. [PubMed: 9523785]
23. Lewis, C.; Bottomley, J. Musculoskeletal changes with age. In: Lewis, C., editor. Aging: health care's challenge. 2. Philadelphia: FA Davis; 1990. p. 145-6.
24. Henry SM, Fung J, Horak FB. Control of stance during lateral and anterior/posterior surface translations. IEEE Trans Rehabil Eng 1998;6:32–42. [PubMed: 9535521]
25. Rietdyk S, Patla AE, Winter DA, Ishac MG, Little CE. Balance recovery from medio-lateral perturbations of the upper body during standing. J Biomech 1999;32:1149–58. [PubMed: 10541064]
26. Winter, DA. ABC: anatomy, biomechanics and control of balance during standing and walking. Waterloo: Waterloo Biomechanics; 1995.
27. Rogers MW, Pai YC. Dynamic transitions in stance support accompanying leg flexion movements in man. Exp Brain Res 1990;81:398–402. [PubMed: 2397765]
28. MacKinnon CD, Winter DA. Control of whole body balance in the frontal plane during human walking. J Biomech 1993;26:633–44. [PubMed: 8514809]
29. Cho BL, Scarpace D, Alexander NB. Tests of stepping as indicators of mobility, balance, and fall risk in balance-impaired older adults. J Am Geriatr Soc 2004;2:1168–73. [PubMed: 15209657]
30. Shumway-Cook A, Gruber W, Baldwin M, Liao S. The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults. Phys Ther 1997;77:46–57. [PubMed: 8996463]
31. Tinetti ME. Clinical practice. Preventing falls in elderly persons. N Engl J Med 2003;348:42–9. [PubMed: 12510042]

32. Jobges M, Heuschkel G, Pretzel C, Illhardt C, Renner C, Hummelsheim H. Repetitive training of compensatory steps: a therapeutic approach for postural instability in Parkinson's disease. J Neurol Neurosurg Psychiatry 2004;75:1682–7. [PubMed: 15548482]

33. Protas EJ, Mitchell K, Williams A, Qureshy H, Caroline K, Lai EC. Gait and step training to reduce falls in Parkinson's disease. NeuroRehabilitation 2005;20:183–90. [PubMed: 16340099]

Table 1

Comparison of Age, Protective Stepping, Trunk Motion, and Hip Torque Outcome Variables

Variable	Fallers (n=19)	Nonfallers (n=32)	*P*
Age (y)	74.8±7.3	72.4±5.6	.229*
% Multiple steps	0.84±0.31	0.68±0.32	.018†
% Crossover steps	0.71±0.27	0.67±0.31	.783†
Global step length (cm)	34.0±13.9	46.1±12.3	.003*
FAR physical (deg)	203.4±34.5	232.7±33.7	.006*
FAR visual (deg)	287.6±34.6	314.7±30.6	.008*
Peak isokinetic hip abductor torque ($Nm \cdot kg^{-1} \cdot m^{-1}$)	0.48±0.16	0.61±0.15	.008*

NOTE. Values are mean ± SD.

* Two-sample *t* test.

† Kruskal-Wallis test.

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Table 2

Potential Predictors of a Fall During 1-Year Prospective Follow-Up: Single Variable Models

Predictor Variable	OR	1/Odds	95% CI for OR	*P*
100% multiple steps	6.16		1.74–21.8	.005
Global step length		2.03	1.23–3.34	.006
FAR physical/30		2.24	1.21–4.15	.010
FAR visual/30		2.23	1.20–4.15	.011
Peak isokinetic hip abductor torque ×10		1.79	1.13–2.82	.012

Abbreviations: CI, confidence interval; FAR/30, functional axial rotation divided into 30° increments; OR, odds ratio.

Table 3

Sensitivity, Specificity, and Predictive Values for Prospective Falls Within 1 Year

Cutoff Scores	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value
One predictor variable				
100% multiple steps*				
Multiple steps in all trials	74	69	58	81
FAR physical†				
<210° of trunk axial motion	63	77	63	77
Peak isokinetic hip abductor torque*				
<55% of normalized torque (body weight × height)	74	66	56	81
Two predictor variables				
FAR physical isokinetic hip abductor†				
>40% calculated probability of falling using logistic regression equation	68	77	65	80

NOTE. Values are percent.

*n =51 subjects.

†n=50 subjects.