Journal of Gerontology: MEDICAL SCIENCES
2001, Vol. 56A, No. 10, M627–M632

Choice Stepping Reaction Time: A Composite Measure of Falls Risk in Older People

Stephen R. Lord and Richard C. Fitzpatrick

Prince of Wales Medical Research Institute, Sydney, Australia.

Background. This study investigated the neuropsychological, sensorimotor, speed, and balance contributions to a new test of choice stepping reaction time (CSRT) and determined whether this new test is an important predictor of falls in older people.

Methods. A total of 477 retirement-village residents aged 62 to 95 years (mean ± *SD*, 79.2 ± 6.2 years) took the CSRT test, which required them to step onto one of four panels that were illuminated in a random order. The subjects also took tests that measured neuropsychological, sensorimotor, speed, and balance function.

Results. Multiple regression analysis revealed that poor performance in Part B of the Trail Making Test (a neuropsychological test) and impaired quadriceps strength, simple reaction time, sway with eyes open on a compliant surface, and maximal balance range were the best predictors of increased CSRTs (multiple $r^2 = .45$). Subjects with a history of falls had significantly increased CSRTs compared with nonfallers (1322 ± 331 milliseconds and 1168 ± 203 milliseconds, respectively). Impaired CSRT was a significant and independent predictor of falls, as were two complementary sensory measures (visual contrast sensitivity and lower limb proprioception). Of these measures, CSRT was the most important in predicting falls. Furthermore, the inclusion of CSRT in the model excluded measures of strength, central processing speed, and balance, because these could not provide nonredundant information for the prediction of falls.

Conclusions. This study identifies a new test that provides a composite measure of falls risk in older people and elucidates the relative importance of specific physiological and neuropsychological systems in the initiation of fast and appropriate step responses.

AVOIDING a fall requires perception of a postural threat, selection of an appropriate corrective response, and proper response execution (1). The individual physiological components required to avoid falls—sensory acuity, reaction time, and reactive stepping—have been individually investigated in relation to aging and falls risk in older people.

There is considerable evidence that sensory acuity declines with age (2,3) and that older fallers have impaired sensory acuity compared with nonfallers (4–7). Many studies have also found that simple reaction time (SRT) increases with age (8). Most of these studies have used a finger press as the response, a task that emphasizes the decision time component. However, other studies have also examined the relationship between reaction time and aging involving movements of the lower limb and the whole body. In such tasks, there are notable age-related increases in movement time in addition to age-related increases in decision time (9,10).

In previous studies of older people, we have found that increased finger-press SRT is a significant and independent risk factor for falls (5–7). It has also been found that finger-press choice reaction time (CRT) discriminates between elderly people who have and have not fallen (11) and who have and have not suffered fall-related fractures (12). Grabiner and Jahnigen (13) have also reported that fallers are significantly slower than nonfallers in SRT and CRT tests that involve more complicated motor responses, such as extending and flexing the knee.

Most research on stepping behavior in older people has examined stepping responses to postural disturbances. In one study, Thelen and colleagues (14) found that, compared with younger men, older men were unable to take a single step to regain balance after being released from a harness that held them in a forward-leaning position. Other studies have used platform translations and waist pulls to disturb balance. These studies have found that such disturbances cause older people to step more laterally and to take more steps than younger people (15) and cause older fallers to step more laterally than nonfallers (16).

However, in addition to reduced sensory acuity, slow reaction time, and poor stepping responses, reduced functioning in lower limb strength and standing and leaning balance have been shown to increase falls risk in older people (5–7,17–19). Furthermore, it has also been shown that older people with attention impairments have reduced balance (20–22) and an increased risk of falls (11,23,24).

To date, only one study has investigated the determinants of voluntary stepping reaction time (25). This study showed that older people are slower in a choice stepping reaction time (CSRT) test involving three possible responses and that this age-related difference was due to increases in both initiation and weight transfer times. However, this study was limited to a single-leg stepping response, and subjects knew before each trial the weight transfer required. In the present study, we devised a test of CRT that requires steps from either leg and thus body weight and balance transfers that are not unlike the step responses required to avoid a fall. We measured the extent to which particular neuropsychological, sensorimotor, and balance impairments were associated with poor performance in this test and whether older people with slow CRTs were at an increased risk of falls.

Methods

Subjects

A total of 477 subjects aged 62 to 95 years (mean ± *SD*, 79.2 ± 6.2) who underwent the CSRT test and who had MMSE scores >20 (26) comprised the study sample. The age and sex distribution is shown in Table 1. The subjects were residents of retirement villages in Sydney, Australia, who took part in a randomized, controlled trial of group exercise on falls risk factors. A total of 401 subjects (84.1%) were living in self-care units, and 76 (15.9%) were living in intermediate-care hostels. Table 2 shows the prevalence of major medical conditions, medication use, physical activity, mobility, and activities of daily living limitations in the study population.

To determine CSRTs in younger persons, 30 subjects (15 men and 15 women) aged 25 to 44 years (mean ± *SD*, 30.2 ± 5.8) with no neurological or musculoskeletal conditions also took this test.

Measurement of CSRT

Subjects stood on a nonslip black platform (0.8 m × 0.8 m) that contained four rectangular panels (32 cm × 13 cm), one in front of each foot and one to the side of each foot. The panels were illuminated in a random order. Subjects were instructed to step onto the illuminated panel as quickly as possible, using the left foot only for the two left panels (front and side) and the right foot only for the two right panels. Each panel contained a pressure switch to determine the time of foot contact. Subjects stood with their feet 10 cm apart and in line with the two side panels. Subjects had between four and eight practice trials involving the four possible responses. Twenty trials were then conducted with five trials for each of the four stepping responses. All trials were included in the analysis because anticipation was not helpful in this test due to the subjects being equally likely or unlikely to predict which leg was required for each step. CSRT was measured as the time period between the illumination of a panel and the foot making contact with it, and the average time of the 20 trials was used in the analysis. The CSRT device is shown in Figure 1.

Table 1. Age and Sex Distribution of the Sample

	Men		Women		Total	
Age Group	*n*	(%)	*n*	(%)	*n*	(%)
62–69	4	(5.6)	22	(5.4)	26	(5.5)
70–74	12	(16.9)	77	(19)	89	(18.7)
75–79	15	(21.1)	109	(26.8)	124	(26)
80–84	26	(36.6)	126	(31)	152	(31.9)
85–89	11	(15.5)	50	(12.3)	61	(12.8)
90+	3	(4.2)	22	(5.4)	25	(5.2)
Total	71	(100)	406	(100)	477	(100)
Mean (*SD*)	79.6	(6.2)	79.1	(79.1)	79.2	(6.2)

Table 2. Prevalence of Major Medical Conditions, Medication Use, Participation in Physical Activity, and Mobility and ADL Limitations in the Study Population

Condition	*n*	%
Medical Conditions		
Poor vision	111	23.3
Poor hearing	178	37.3
Stroke	47	9.9
Heart disease	145	30.4
Poor circulation	192	40.3
High blood pressure	250	52.4
Low blood pressure	64	13.4
Respiratory conditions	97	20.3
Arthritis	313	66.6
Diabetes	40	8.4
Foot problems	126	26.4
Medication Use		
Four or more medications	246	66.7
Cardiovascular system medications	318	65.4
Psychoactive medications	161	33.8
Musculoskeletal system medications	103	21.6
Physical Activity		
Planned walks at least once per week	324	67.9
Walked more than 3 h per week	147	30.8
Mobility and ADL Limitations		
Used a walking aid	136	28.52
Difficulty shopping	101	21.2
Difficulty with clothes washing or room cleaning	36	7.5
Difficulty cooking	78	16.5
Difficulty dressing	10	2.1
Difficulty bathing or toileting	9	1.9

Note: ADL = activity of daily living.

Sensorimotor Function and Balance Assessments

Visual contrast sensitivity was assessed using the Melbourne Edge Test (27). Proprioception was measured using a lower-limb–matching task. Errors were recorded using a protractor inscribed on a vertical clear acrylic sheet (60 cm × 60 cm × 1 cm) placed between the legs. Ankle dorsiflexion and quadriceps strength were measured in both legs with the subjects seated (28). The angles of the hip, knee, and ankle were 90°, 110°, and 90°, respectively, when testing ankle dorsiflexion strength, and the angles of the hip and knee were 90° when testing quadriceps strength (28). The best of three trials was recorded for both muscle groups, and the average of these scores for both legs was recorded. Simple reaction time was measured using a light as the stimulus and a finger-press as the response. A finger-press SRT test was used to obtain a measure that emphasized the decision time component of reaction time (i.e., it required only a minimal motor response [a light tap of a finger]). Postural sway was measured using a swaymeter that measured displacements of the body at the level of the waist. Testing was performed with subjects standing on the floor and on a foam rubber mat (40 cm × 40 cm × 7.5 cm thick) with eyes open and eyes closed. Leaning balance was measured using the maximal balance range (29) and coordinated stability tests (29). The validity and reliability of these tests have been established in previous studies (5–7,29–31).

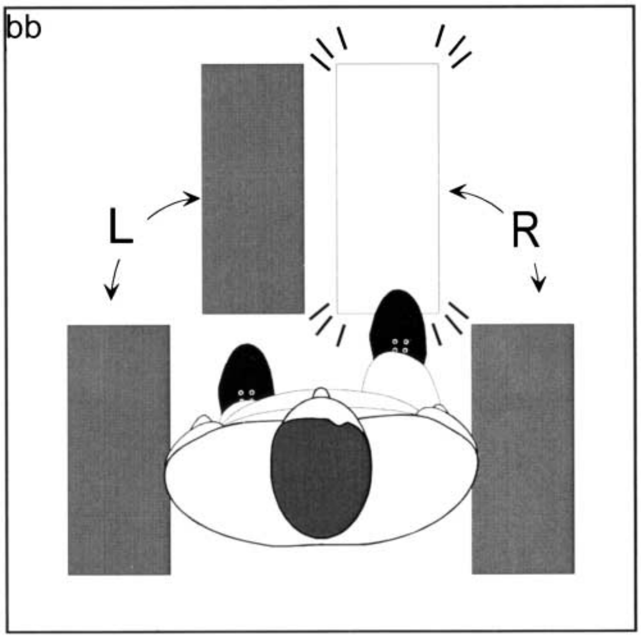

Figure 1. Choice stepping reaction time (CSRT) device.

Neuropsychological Assessments

Three neuropsychological tests were administered. The digit symbol test required subjects to copy symbols that were paired with numbers within a 90-second time limit (32). The Stroop Color-Word Test (33) required subjects to state the color of the ink of 112 printed words while ignoring the meaning of the word itself within 120 seconds. The Trail Making Test (TMT) (34) had two parts. Part A required subjects to draw lines connecting numbered circles, and Part B required subjects to connect the same number of circles, alternating between letters and numbers. The time taken to complete the tests was measured.

Falls

The number of falls suffered by the subjects in the 12 months before assessment was recorded. Falls were ascertained retrospectively because more than half of the sample was randomized to an exercise intervention program and were therefore contaminated with respect to a falls risk-factor study. A fall was defined as "an event which resulted in a person coming to rest unintentionally on the ground or other lower level, not as the result of a major intrinsic event or an overwhelming hazard" (6).

Statistical Analysis

The neuropsychological, sensorimotor, and balance measures were continuous variables. For variables with right-skewed distributions, logs of the variables were analyzed. Correlation coefficients were computed to examine the relationships between CSRT and age and the other test variables. Forward stepwise regression was used to assess the associations between CSRT and the neuropsychological, sensorimotor, and balance variables. Age was then forced into the model to assess whether this variable could explain further variance in CSRT. Standardized beta weights are provided to give an indication of the relative importance of the various system variables entered into the model in explaining variance in CSRT. Differences between the means of CSRT and other measures between fallers and nonfallers were assessed using independent samples t tests. Finally, a stepwise discriminant analysis was undertaken to identify the best set of independent variables for discriminating between the fallers and nonfallers. The data were analyzed using SPSS for Windows (35).

Results

CSRT and Age and Sex

The mean CSRT in the older population was 1264 ± 268 milliseconds, which was significantly slower than the younger group, which had a mean CSRT of 744 ± 97 milliseconds ($t_{505} = 12.95$, $p < .001$). Age was also significantly correlated with CSRT within the older population ($r = 0.38$, $p < .001$). The older men had significantly faster CSRTs than the older women (1157 ± 314 milliseconds and 1236 ± 257 milliseconds, respectively; $t_{475} = -3.05$, $p < .01$), and this difference remained significant after adjusting for quadriceps and ankle dorsiflexion strength in an ANCOVA procedure ($F_{1,462} = 5.80$, $p < .05$).

Neuropsychological, Sensorimotor, and Balance Correlates of CSRT

Table 3 shows the associations (r) between CSRTs and the neuropsychological and sensorimotor function and balance measures. All of these measures were significantly associated with CSRT performance, with the exception of proprioception and sway with eyes open standing on the floor.

The stepwise multiple regression analyses revealed that the score from Part B of the TMT, quadriceps strength, SRT, sway with eyes closed on foam, and maximal balance range were significant and independent predictors of CSRT performance. The beta weights, presented in Table 4, indicate that quadriceps strength, SRT, and maximal balance range explained larger proportions of the variance in CSRT

Table 3. Sensorimotor and Balance Correlates of CSRT

Sensorimotor and Balance Measures	*R*
Digit symbol (383)	−.36**
Stroop CW (267)	−.36**
Trails A (449)	.33**
Trails B (448)	.36**
Visual contrast sensitivity	−.29**
Proprioception	.08
Ankle dorsiflexion strength	−.42**
Quadriceps strength	−.51**
Simple reaction time	.41**
Sway: eyes open on floor	.04
Sway: eyes closed on floor	.11*
Sway: eyes open on foam	.25**
Sway: eyes closed on foam	.28**
Maximum balance range	−.50**
Coordinated stability	.42**

Note: CSRT = choice stepping reaction time.
*$p < .05$; **$p < .01$.

Table 4. Predictor Variables of CSRT and Their Beta Weights

Predictor Variables	Beta Weights	r^2
Trails B score	0.12	.450**
Quadriceps strength	0.33	
Simple reaction time	0.20	
Sway: eyes closed on foam	0.14	
Maximal balance range	−0.25	
Age		.454

Note: Asterisks indicate significant differences in r^2 change when blocks of variables are entered into the regression equations: $^{**}p < .01$. The physiological variables identified as significant and independent contributors to r^2 (at $p < .05$) in a stepwise procedure were included in the initial block. Age was then forced into the model to determine how much further variance in choice stepping reaction times this variable could explain.

than did the score from Part B of the TMT or sway. The model explained 45.0% of the variance in CSRT (multiple $r =$ .67). The subsequent inclusion of age into the model added only a small and nonsignificant amount (0.4%; $p = .08$) to the explained variance in CSRT.

CSRT and Falls

A total of 303 subjects (63.5%) reported not falling in the year before assessment, whereas 174 subjects (36.5%) reported one or more fall*s*. Of those who fell, 174 fell once, and 57 fell on two or more occasions. The mean age of the fallers was slightly but not significantly greater than the mean age of the nonfallers (78.8 ± 6.2 years and 79.9 ± 6.2 years, respectively; $t_{475} = 1.82$, $p = .07$).

Table 5 shows the mean values and standard deviations for the CSRT and other test measures for the fallers and nonfallers. Compared with the nonfallers, the fallers had significantly increased CSRTs and impaired performance in the neuropsychological, sensorimotor, speed, and balance tests, with the exception of sway with eyes open or eyes closed standing on the floor.

Table 5. Test Measures and Falling

Test	Fallers Mean	Fallers (*SD*)	Nonfallers Mean	Nonfallers (*SD*)
Stepping choice reaction time, ms	1322	(331)**	1168	(203)
Digit symbol	32.8	(9.4)**	36.1	(9.9)
Stroop CW	65.0	(26.4)**	74.1	(22.3)
Trails A	54.7	(20.7)**	49.8	(18.6)
Trails B	70.6	(48.1)**	58.4	(33.6)
Visual contrast sensitivity, dB	17.5	(3.2)**	18.7	(3)
Proprioception, degrees error	2.0	(1.4)**	1.8	(1.4)
Quadriceps strength, N	209	(92)**	234	(91)
Ankle dorsiflexion strength, N	52	(22)**	59	(24)
Simple reaction time, ms	297	(64)**	281	(49)
Sway: eyes open on floor, mm	106	(53)	104	(59)
Sway: eyes closed on floor, mm	145	(86)	129	(70)
Sway: eyes open on foam, mm	164	(95)*	147	(85)
Sway: eyes closed on foam, mm	257	(138)**	217	(104)
Maximal balance range, mm	148	(42)**	161	(38)
Coordinated stability, error score	18.0	(11)**	14.8	(9.4)

Note: Low scores in the visual contrast sensitivity, strength tests, and maximal balance and high scores in all other tests indicate impaired performance.
$^{*}p < .05$; $^{**}p < .01$.

The discriminant analysis revealed that CSRT was a significant and independent risk factor for falls. With CSRT in the model, no measures of strength, speed, or balance met the inclusion criteria because their correlations with CSRT were too high. However, visual contrast sensitivity and proprioception entered the model, and these variables with CSRT discriminated significantly between the faller and nonfaller groups (Wilk's $\lambda = .90$, $p < .001$; canonical correlation = 0.32). The standardized canonical correlation coefficients were 0.67 for CSRT, −0.44 for visual contrast sensitivity, and 0.42 for proprioception. These variables correctly classified 64% of the cases with similar sensitivity and specificity.

The significant differences found in the test measures between the fallers and nonfallers were also found when comparing multiple (≥2 falls) fallers and nonmultiple (0 or 1 fall) fallers in the follow-up period, with few exceptions. The multiple–non-multiple faller comparisons showed significant differences in the sway on floor tests with eyes open and closed ($t_{475} = 1.96$, $p < .05$ and $t_{475} = 3.00$, $p <$ .01, respectively) but no significant differences in the tests of proprioception or maximal balance range.

Discussion

The CSRT test that we used as a model for risk of falling contains a volitional, or attention, component. Thus, it differs from the response to perturbation models often used to assess balance control in older people (13,18,36). Although these tests have revealed significant age-related differences, they have not been found to be strong predictors of falls, with two studies finding that simple measures of unperturbed sway are better able to distinguish fallers from nonfallers than measures of response to perturbation (18,36). In contrast, we found that slow CSRT was the strongest predictor of falls from an extensive range of neuropsychological, sensorimotor, and balance measures, which suggests that impaired voluntary stepping may contribute to many falls.

The inclusion of a volitional or attention component within a falls risk model is supported by recent research that has used divided attention tasks in studies of balance control (20–22) and prediction of falls (11,23,24). These studies have found that asking older people to count backward or answer a question can impair balance and gait. Thus, even standing, usually considered a "reflex" activity, requires cognitive input in older people with balance disorders, and as balance tasks become more challenging, the attention requirements increase correspondingly (21,23).

In this study, performances in four neuropsychological tests were associated with CSRT. These tests assessed cognitive processes relevant to spatial working memory and attention (i.e., motor persistence, sustained attention, response speed, and visuomotor coordination [Digit symbol], visual conceptual and visuomotor tracking [TMT Parts A and B], and ability to cope with response conflict and selective attention [STROOP Color Word]). These findings are consistent with those of Maylor and Wing (20) who found that cognitive tasks requiring spatial skills and spatial working memory have the greatest effects on balance control.

Older subjects performed worse than younger subjects in the CSRT test. This was evident in both the pronounced differences in CSRTs between the young and older sample and in the significant correlation between CSRTs and age within the older group. Interestingly, the older women also performed significantly worse than the older men. Such a gender difference is not evident for most neuropsychological, sensorimotor, and balance measures, where the only consistent difference found is that older men are stronger than older women (37). The finding that older women also have slower CSRTs, after controlling for lower limb strength, suggests an additional explanation for the higher falling rates in women.

The significant associations between the neuropsychological, sensorimotor, and balance measures and performance in the CSRT test suggests that all these factors may play important roles in the initiation and control of quick, accurate steps. This is consistent with the findings of Patla and colleagues (25), who found that both central (initiation time) and peripheral factors (weight transfer time) were important in a single-leg CSRT test and that both of these factors showed age-related changes. The results of the multiple regression analysis indicate that lower limb muscle weakness, slow SRT, and poor leaning balance in particular impair CSRT. Furthermore, these measures account for a large part of the variance in CSRT and nearly all of the age-related variance in CSRT. This indicates that an appropriate array of measures was used as possible predictors.

CSRT was also identified as an independent and significant predictor of falls, as were two complementary sensory measures, visual contrast sensitivity and lower limb proprioception. Of these measures, CSRT had the largest standardized discriminant function coefficient, indicating that this measure was the most important in predicting falls. Furthermore, due to high inter-correlations, the inclusion of CSRT prevented measures of strength, central processing speed, and balance entering the model. Thus, although poor performance in these measures has been found to be significantly associated with falls in this and previous studies (5–7), they did not provide nonredundant information for discriminating between fallers and nonfallers in this sample. Therefore, in terms of the three-stage response model for falls avoidance (1,13), visual contrast sensitivity and lower limb proprioception are involved in the perception of postural threats, and CSRT provides a composite measure for the neuropsychological, sensorimotor, and balance factors required for the selection and execution of appropriate corrective balance responses.

The correct classification of fallers and nonfallers of 64% is less than we have reported in previous studies of falls risk in older people (5–7). This may be primarily due to the retrospective nature of the study that was required because of the intervention component of the study. Consequently, there was a probable under-reporting of falls due to the limited accuracy of recalling falls over a 12-month period (38). This may have weakened the association between falls and CSRT as well as with the other measures. It is also acknowledged that because falls incidence was recorded retrospectively, the reduced stepping ability in the fallers may have been due in part to their history of falling. However, recent large prospective studies have found strong associations between past falls and subsequent falls (39,40), so the impairments found here are likely to have implications for further falls.

In conclusion, the study identifies a new test that provides a composite measure of falls risk in older people and elucidates the roles of specific neuropsychological, sensorimotor, speed, and balance factors in the initiation of fast and appropriate step responses.

Acknowledgments

This study was funded by the National Health and Medical Research Council of Australia, New South Wales Health and MBF (Australia). We thank Joanne Corcoran, Julia Dayhew, Amelia Howland, Beth Matters, and Philippa Williams for their assistance in this study.

Address correspondence to Dr. Stephen Lord, Prince of Wales Medical Research Institute, High Street, Randwick, NSW, 2031, Australia. E-mail: s.lord@unsw.edu.au

References

1. Stelmach GE, Worringham CJ. Sensorimotor deficits related to postural stability: implications for falling in the elderly. *Clin Geriatr Med.* 1985;1:679–694.
2. Pitts DG. The effects of aging on selected visual functions: dark adaptation, visual acuity, stereopsis, brightness contrast. In: Sekuler R, Kline DW, Dismukes K, eds. *Aging in Human Visual Functions*. New York: Liss; 1982.
3. Kenshalo DR. Somesthetic sensitivity in young and elderly humans. *J Gerontol.* 1986;41:732–742.
4. Ivers RQ, Cumming RG, Mitchell P, Attebo K. Visual impairment and falls in older adults: the Blue Mountains Eye Study. *J Am Geriatr Soc.* 1998;46:58–64.
5. Lord SR, Clark RD, Webster IW. Physiological factors associated with falls in an elderly population. *J Am Geriatr Soc.* 1991;39:1194–1200.
6. Lord SR, Ward JA, Williams P, Anstey K. Physiological factors associated with falls in older community-dwelling women. *J Am Geriatr Soc.* 1994;42:1110–1117.
7. Lord SR, Clark RD. Simple physiological and clinical tests for the accurate prediction of falling in older people. *Gerontology.* 1996;42: 199–203.
8. Welford AT. Motor performance. In: Birren JE, Schaie KW, eds. *Handbook of the Psychology of Aging.* New York: van Nostrand Reinhold Company; 1977.
9. Onishi N. Changes of the jumping reaction time in relation to age. *J Sci Lab.* 1966;42:5–16.
10. Spurduso WW. Reaction and movement time as a function of age and physical activity level. *J Gerontol.* 1975;30:435–440.
11. Woolley SM, Czaja SJ, Drury CG. An assessment of falls in elderly men and women. *J Gerontol Med Sci.* 1997;52A:M80–M87.
12. Adelsberg S, Pitman M, Alexander H. Lower extremity fractures: relationship to reaction time and coordination time. *Arch Phys Med Rehabil.* 1989;70:737–739.
13. Grabiner MD, Jahnigen DW. Modeling recovery from stumbles: preliminary data on variable selection and classification efficacy. *J Am Geriatr Soc.* 1992;40:910–913.
14. Thelen DG, Wojcik LA, Schultz AB, Ashton-Miller JA, Alexander NB. Age differences in using a rapid step to regain balance during a forward fall. *J Gerontol Med Sci.* 1997;52A:M8–M13.
15. McIlroy WE, Maki BE. Age-related changes in compensatory stepping in response to unpredictable perturbations. *J Gerontol Med Sci.* 1996;51A:M289–M296.
16. Rogers MW. Disorders of posture, balance, and gait in Parkinson's disease. In: Studenski S, ed. *Clinics in Geriatric Medicine: Gait and Balance Disorders*. Philadelphia, PA: WB Saunders Company; 1996.
17. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. *J Am Geriatr Soc.* 1987;35:13–20.
18. 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.
19. 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.
20. Maylor EA, Wing AM. Age differences in postural stability are increased by additional cognitive demands. *J Gerontol Psych Sci.* 1996; 51B:P143–P154.
21. Brown LA, Shummway-Cooke A, Woollacott MH. Attentional demands and postural recovery: the effects of aging. *J Gerontol Med Sci.* 1999;54A:M165–M171.
22. Simoneau M, Teasdale N, Bourdin C, Bard C, Fleury M, Nougier V. Aging and postural control: postural perturbations caused by changing the visual anchor. *J Am Geriatr Soc.* 1999;47:235–240.
23. Shumway-Cook A, Woollacott M, Kerns KA, Baldwin M. The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *J Gerontol Med Sci.* 1997;52A:M232–M240.
24. Lundin-Olsson L, Nyberg L, Gustafson Y. "Stops walking while talking" as a predictor of falls in elderly people. *Lancet.* 1997;349:617.
25. Patla AE, Frank JS, Winter DA, Rietdyk S, Prentice S, Prasad S. Age-related changes in balance control system: initiation of stepping. *Clin Biomech.* 1993;8:179–184.
26. Folstein MF, Folstein SE. Mini-Mental State: a practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res.* 1975;12:189–198.
27. Verbaken JH, Johnston AW. Population norms for edge contrast sensitivity. *Am J Opt Physiol Optics.* 1986;63:724–732.
28. Lord SR, Ward JA, Williams P, Strudwick M. The effect of a 12 month exercise program on balance, strength and falls in older women: a randomised controlled trial. *J Am Geriatr Soc.* 1995;43:1198–1206.
29. Lord SR, Ward JA, Williams P. The effect of exercise on dynamic stability in older women: a randomized controlled trial. *Arch Phys Med Rehabil.* 1996;77:232–236.
30. Lord SR, Clark RD, Webster IW. Postural stability and associated physiological factors in a population of aged persons. *J Gerontol Med Sci.* 1991;46:M69–M76.
31. Lord SR, Castell S. The effect of a physical activity program on balance, strength, neuromuscular control and reaction time in older persons. *Arch Phys Med Rehabil.* 1994;75:648–652.
32. Lezak MD. *Neuropsychological Assessment*. 3rd ed. New York: Oxford University Press; 1995.
33. Trenerry MR, Crosson BC, DeBoe J, Leber WR. *Stroop Neuropsychological Screening Test.* Lutz, FL:Psychological Assessment Resources; 1988.
34. Spreen O, Strauss E. *A Compendium of Neuropsychological Tests*. New York: Oxford University Press; 1991.
35. SPSS Inc. *SPSS for Windows Base System User's Guide*. Chicago, IL: SPSS Inc; 1993.
36. Maki BE, Holliday PJ, Fernie GR. Aging and postural control: a comparison of spontaneous- and induced-sway balance tests. *J Am Geriatr Soc.* 1990;38:1–9.
37. Murray MP, Duthie EH, Gambert SR, Sepic SB, Mollinger LA. Age related differences in knee muscle strength in normal women. *J Gerontol.* 1985;40:275–280.
38. 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.
39. 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.
40. 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.

Received June 30, 2000
Accepted August 17, 2000
Decision Editor: John E. Morley, MB, BCh