Effectiveness of a Targeted Exercise Intervention in Reversing Older People's Mild Balance Dysfunction: A Randomized Controlled Trial

Xiao Jing Yang, Keith Hill, Kirsten Moore, Susan Williams, Leslie Dowson, Karen Borschmann, Julie Anne Simpson, Shyamali C. Dharmage

X.J. Yang, MBBS, MWomen'sHlth, MHlthSci, School of Population Health, University of Melbourne, Carlton, Victoria, Australia. Address all correspondence to Dr Yang at: jing@nari.unimelb.edu.au.

K. Hill, BAppSc(Physio), GradDip Physio, PhD, La Trobe University and Northern Health, Melbourne, Victoria, Australia.

K. Moore, BA(Hons), National Ageing Research Institute, Parkville, Victoria, Australia.

S. Williams, BSci, BAppSci(Phyt), MPhysio, National Ageing Research Institute.

L. Dowson, BSc(Hons), MBioethics, National Ageing Research Institute.

K. Borschmann, BPhysio, National Ageing Research Institute.

J.A. Simpson, BSc, PGradDipMath Stat, PhD, Centre for Molecular, Environmental, Genetic & Analytic Epidemiology, School of Population Health, University of Melbourne.

S.C. Dharmage, MBBS, MSc, MD, PhD, Centre for Molecular, Environmental, Genetic & Analytic Epidemiology, School of Population Health, University of Melbourne.

[Yang XJ, Hill K, Moore K, et al. Effectiveness of a targeted exercise intervention in reversing older people's mild balance dysfunction: a randomized controlled trial. *Phys Ther.* 2012;92:24–37.]

Published Ahead of Print: October 6, 2011
Accepted: July 26, 2011
Submitted: August 30, 2010

Background. Previous research has mainly targeted older people with high risk of falling. The effectiveness of exercise interventions in older people with mild levels of balance dysfunction remains unexplored.

Objective. This study evaluated the effectiveness of a home balance and strength exercise intervention in older people systematically screened as having mild balance dysfunction.

Design. This was a community-based, randomized controlled trial with assessors blinded to group allocation.

Participants. Study participants were older people who reported concerns about their balance but remained community ambulant (n=225). After a comprehensive balance assessment, those classified as having mild balance dysfunction (n=165) were randomized into the trial.

Intervention. Participants in the intervention group (n=83) received a 6-month physical therapist–prescribed balance and strength home exercise program, based on the Otago Exercise Program and the Visual Health Information Balance and Vestibular Exercise Kit. Participants in the control group (n=82) continued with their usual activities.

Outcome Measures. Laboratory and clinical measures of balance, mobility, and strength were assessed at baseline and at a 6-month reassessment.

Results. After 6 months, the intervention group (n=59) significantly improved relative to the control group (n=62) for: the Functional Reach Test (mean difference=2.95 cm, 95% confidence interval [CI]=1.75 to 4.15), the Step Test (2.10 steps/15 seconds, 95% CI=1.17 to 3.02), hip abductor strength (0.02, 95% CI=0.01 to 0.03), and gait step width (2.17 cm, 95% CI=1.23 to 3.11). There were nonsignificant trends for improvement on most other measures. Fourteen participants in the intervention group (23.7%) achieved balance performance within the normative range following the exercise program, compared with 3 participants (4.8%) in the control group.

Limitations. Loss to follow-up (26.6%) was slightly higher than in some similar studies but was unlikely to have biased the results.

Conclusions. A physical therapist–prescribed home exercise program targeting balance and strength was effective in improving a number of balance and related outcomes in older people with mild balance impairment.

Balance is defined as the ability to maintain the projection of the body's center of mass within limits of the base of support, as in standing or sitting, or in transit to a new base of support, as in walking.[1] Balance control is complex and multifactorial. Physiological changes related to aging include reduction in muscle strength,[2] joint range of motion, reaction time, and changes in sensory systems.[3,4] These factors, combined with pathology affecting these systems, potentially have negative effects on older people's balance control and may lead to balance dysfunction of varying severity.

Management of older people's balance dysfunction plays a key role in fall prevention. Impaired balance and reaction time, as well as loss of lower-limb muscle strength, have been identified as important risk factors for falls in older people.[5,6] These factors have been shown to be amenable to interventions that can be carried out in the community setting.[7]

Published trials have shown that exercise interventions with balance and muscle strengthening components are effective in reducing falls[8–10] and in improving physiological and functional performance in older people.[11] Most published studies evaluating effectiveness of exercise programs have either targeted "healthy, active older people,"[12,13] without clear classification, or selected samples of older people with moderate to severe levels of balance dysfunction. These samples include frail older people with multiple functional limitations,[14,15] older people residing in institutions,[16,17] and older people with specific conditions such as stroke[18,19] or Parkinson disease,[20] a history of falls or multiple falls,[21,22] or established risk factors for falls.[23–26]

Falls often are used as a trigger to review risk factors (including balance) to determine whether interventions are needed.[27] However, there has been recent interest in approaches to identifying problems contributing to falls before balance impairment becomes more marked and a fall occurs.[28–30] Curb and colleagues described a need for tests to discriminate performance on the "gradient of functioning at the upper end of the functional spectrum."[31(p738)] Using responsive tests of balance performance to identify mild levels of balance impairment could meet this need and identify people who without intervention would be likely to progress to becoming a "faller." Furthermore, from a health promotion and prevention perspective, an exercise intervention introduced when balance dysfunction has recently developed or is of a mild level of severity may be more effective, less expensive, or both,[32] than implementing intervention at a late stage, when more advanced balance dysfunction or falls are occurring.

There is a lack of research into older people with mild levels of balance dysfunction, and the effectiveness of exercise interventions in this group is unknown. Therefore, the current study aimed to investigate the effectiveness of a personalized, home-based exercise program in reversing older people's mild balance dysfunction. The hypothesis tested in this study was that a home exercise program is effective in improving balance performance of older people with identified mild balance dysfunction.

Method

This study was a randomized controlled trial. Clinical and laboratory measures of balance, mobility, gait, and muscle strength were assessed at baseline and at a 6-month reassessment. Participants in the intervention group underwent a personalized, home-based exercise program prescribed by a physical therapist, and participants in the control group continued with their usual activities.

Participants

The sample consisted of 225 community-dwelling men and women aged 65 years and over. Recruitment started in February 2006 and was completed in September 2007. Participants were recruited from metropolitan Melbourne, Australia, by advertising in newspapers and newsletters, as well as through presentations by researchers to community groups of older people. Initially, the project targeted recruitment through veterans' and war widows' agencies. At later stages, recruitment was opened up to include all people aged 65 years or older who met the inclusion criteria.

Eligible participants for this trial were identified by a 2-step process. First, participants were screened prior to the baseline assessment to determine whether they met inclusion criteria. Second, participants were screened in a comprehensive balance assessment, and those who were identified as having mild balance dysfunction were eligible to be included in the trial.

Inclusion criteria were being aged 65 years or over, living in the community, being community ambulant, requiring no walking aid or using a single-point stick only, experiencing no more than one fall in the previous 12 months, and having concerns about balance. Presence of balance concerns as an inclusion criterion was based on participants' positive response to the question: "Are you concerned about your balance?"

All participants who met the inclusion criteria then underwent a comprehensive balance assessment (details of individual measures are contained in the "Outcome Mea-

sures" section). Those who were identified through this assessment as having mild balance dysfunction were enrolled as study participants. For the purposes of this study, the following criteria were used in classifying participants with mild balance dysfunction:

1. Participants who had any abnormal scores on clinical measures (defined as worse than 1 standard deviation from the mean score published for older people who are healthy). For the clinical measures used for this purpose, cutoff scores to indicate mild balance dysfunction were: a Functional Reach Test (FRT) score of less than 26 cm,[33] a Step Test score of less than 13 steps/15 seconds,[34] and a Five-Time Sit-to-Stand Test time of greater than 17.9 seconds.[35]

2. Participants who had more than 3 abnormal scores on the laboratory measures on the NeuroCom Balance Master force platform with long plate (NeuroCom International Inc, Clackamas, Oregon). Age and sex normative limits for these measures are available from a data set provided with the NeuroCom system. From the 6 tests used from the NeuroCom Balance Master (see below), 46 individual scores were derived (excluding composite scores). A small number (3 or fewer) of these scores being outside of normative limits was accepted as being indicative of normative balance performance, whereas 4 or more of the 46 measures being outside of normative limits was considered to indicate mild balance dysfunction.

Outcome Measures

The primary outcome measures of the trial were clinical and laboratory measures of balance performance, and the secondary outcome measures included measures of strength and mobility, activity level, health-related quality of life, and fear of falling. Balance performance has been shown to be multidimensional, including domains of static balance, bilateral stance dynamic balance, and dynamic single-limb stance balance.[36] Both clinical and computerized forceplate measures (assessed by NeuroCom Balance Master with long plate) of each of these domains of balance were included in the assessment, as there is some evidence that force platform measures may be more sensitive in identifying mild dysfunction[37] and in being responsive to interventions. Given the exploratory nature of this study and in view of the lack of previous studies investigating exercise interventions in older people with mild balance dysfunction, a single primary outcome measure was not selected.

Clinical measures (with retest reliability values from previous studies of older people reported for each test) included:

1. The FRT, a test of dynamic bilateral stance balance.[33] The maximal distance (in centimeters) that a participant could reach forward horizontally was measured while maintaining balance with feet 10 cm apart (intraclass correlation coefficient [ICC]=.81).[33]

2. The Step Test, a test of dynamic single-limb stance balance.[34] The number of times a participant could step one foot fully on and off a 7.5-cm block as quickly as possible in 15 seconds was recorded. The score for the worse side was reported (ICC>.90).[34]

3. The Five-Time Sit-to-Stand Test, a functional measure of lower-limb strength.[35] The participant stood up and sat down as quickly as possible from a standard chair (47 cm high) 5 times, with arms folded across the chest (ICC>.89).[38]

4. Lower-limb muscle strength of individual muscle groups.[39] A handheld dynamometer (Nicholas Manual Muscle Tester, Lafayette Instrument Co, Lafayette, Indiana) was used to measure 3 groups of leg muscles bilaterally using the "break" method: hip abductors, quadriceps, and ankle dorsiflexors.[40] The standardized strength measure for a muscle group was derived by dividing the average of the results of trials 2 and 3 by the participant's weight. The scores on the worse side were reported for the 3 groups of muscles (ICC>.87).[39]

5. Walking speed (meters per minute). The participant was asked to walk at his or her "comfortable walking pace" across a 10-m walkway with the central 6 m timed.[41] Participants used a single-point stick if this was their usual gait aid (ICC>.95).[42]

The NeuroCom Balance Master with long plate also was used to assess balance-related performance during 6 functional tasks. High retest reliability of several of these tests has been reported previously (ICC>.75).[43,44] Test procedures were performed with shoes removed and have been described previously by Vrantsidis and colleagues.[45] The 6 functional tasks were:

1. The Modified Clinical Test of Sensory Interaction on Balance (mCTSIB), a measure of static balance. The mCTSIB quantified postural sway velocity with the participant standing steady on the forceplate under 4 different sensory conditions (standing on a firm surface with eyes open and eyes closed and standing on a foam surface with eyes open and eyes closed). A composite score

(combining the 4 conditions) of center of gravity (COG) sway velocity (in degrees per second) was reported.

2. Limits of stability (LOS), a test of dynamic bilateral stance balance. This test measured the participant's ability to voluntarily control weight shift in 8 directions and to hold as close as possible to a target set at 100% of LOS in each direction. A composite measure for reaction time (in seconds), movement velocity (in degrees per second), and maximum excursion (% of LOS), combining performance in the 8 directions, was reported.

3. Rhythmic weight shift (RWS), a test of dynamic bilateral stance balance. This test was used to examine the participant's ability to coordinate movement of the COG rhythmically forward and backward, while modifying the timing of the COG movement to match the speed of a moving cue at 3 different speeds. A composite score of on-axis velocity (in degrees per second) and direction control (%) across the 3 speeds was reported.

4. Walk across test. This test quantified several characteristics of gait as the participant walked across the forceplate at a comfortable speed. Step width (in centimeters) was reported as a measure of stability during walking.

5. Step quick turn test (SQT). This test quantified the velocity and stability of turning. Three trials turning to the right and 3 trials turning to the left were assessed. A combined score for the 3 trials of the turn time (in seconds) and turn sway (in degrees per second) on the worse side were reported.

6. Stability during the sit-to-stand (STS) maneuver, a functional measure of lower-limb strength. This measure examined the participant's performance in standing up from a 41-cm-high block seat without upper-extremity assistance and his or her stability. A composite score of 3 trials for rising index (percentage of body weight) and COG sway velocity (in degrees per second) was reported.

A project manual recording standardized study procedures and assessment tools was developed. The research team involved in assessing participants was trained by an experienced neurological/gerontological physical therapist to ensure consistency in data collection.

For measures where performance on the worse side was reported, the worse side was determined by the side with the worse score at baseline. For the 6-month reassessment, the same side was used to derive the reassessment score for these measures.

The Human Activity Profile (HAP)[46] was used to measure participants' activity level, and the Adjusted Activity Score (AAS) was reported. The Assessment of Quality of Life (AQoL)[47] was used to measure health-related quality of life. Fear of falling was measured using the Modified Falls Efficacy Scale (MFES).[48] Demographic data, detailed medical history (self-reported conditions diagnosed by a physician) and medication use, and fall history in the previous 12 months (by retrospective recall) also were collected. Although the study was not powered to evaluate falls as an outcome, preliminary information on falls was collected based on participants' self-report (retrospective recall) at the 6-month reassessment.

Sample Size and Protocol Assignment

The LOS measure (maximum excursion composite score), one of the primary outcome measures on the NeuroCom force platform, was selected for calculation of sample size, based on preliminary analysis of our data from a small-sample pilot study and results of a study by Islam et al[49] that indicated the LOS measures were responsive to exercise in an older, "apparently healthy" sample. Using our pilot data (n=12, mean age=76 years), the mean baseline LOS maximum excursion score was estimated as 81 (SD=15). Assuming an expected improvement of 7.5 (ie, 0.5 standard deviation) associated with the intervention, a sample size of 57 participants per group was required (80% power, alpha of .05). This sample size also was sufficient when data for some clinical balance measures (Step Test and FRT) were used. To be able to have 57 participants per study group complete the study, with an expected dropout rate of 20%, we estimated that we needed to recruit 144 participants (72 participants per study arm).

The group allocation schedule was developed by computer-generated random numbers, and the list was managed by a researcher who was not involved in recruiting or assessing participants. Group assignment was made for each participant after the baseline assessment.

Blinding

This study was single-blinded, as only the assessors were blinded to group assignment.

Intervention and Control Group Activities

Intervention participants received a personalized home exercise program developed by an experienced physical therapist. The physical therapist was provided with each

Table 1.
Most Commonly Prescribed Exercises at Each Home Visit[a]

Prescribed Exercises		First Home Visit (n=79)	Second Home Visit (n=76)	Third Home Visit (n=75)
Warm-up exercises (usual dosage: 10 repetitions)	Head movements	79 (100)	76 (100)	73 (97.3)
	Neck movements	52 (65.8)	48 (63.2)	43 (57.3)
	Back extension	78 (98.7)	75 (98.7)	73 (97.3)
	Trunk movements	77 (97.5)	74 (97.4)	71 (94.7)
	Ankle movements	79 (100)	76 (100)	74 (98.7)
Strengthening exercises (usual dosage: 10 repetitions)	Front knee strengthening[b]	16 (20.3)	18 (23.7)	21 (28.0)
	Back knee strengthening[b]	3 (3.8)	4 (5.3)	4 (5.3)
	Side hip strengthening[b]	13 (16.5)	13 (17.1)	13 (17.3)
	Calf raises	27 (34.2)	26 (34.2)	25 (33.3)
	Toe raises	17 (21.5)	16 (21.1)	14 (18.7)
Balance exercises (usual dosage is listed for each exercise)	Knee bends (10 repetitions)	5 (6.3)	5 (6.6)	7 (9.3)
	Backward walking (10 steps, 4 times)	25 (31.6)	17 (22.4)	18 (24.0)
	Walking and turning (twice)	33 (41.8)	33 (43.4)	28 (37.3)
	Sideways walking (10 steps, 4 times)	8 (10.1)	7 (9.2)	10 (13.3)
	Heel-toe stand (10 seconds)	67 (84.8)	67 (88.2)	68 (90.7)
	Heel-toe walking (10 steps)	50 (63.3)	49 (64.5)	51 (68.0)
	One-leg stand (10 seconds)	9 (11.4)	12 (15.8)	13 (17.3)
	Heel walking (10 steps, 4 times)	1 (1.3)	0 (0)	1 (1.3)
	Toe walking (10 steps, 4 times)	3 (3.8)	1 (1.3)	1 (1.3)
	Heel-toe walking backward (10 steps)	21 (26.6)	30 (39.5)	32 (42.7)
	Sit-to-stand (5–10 stands)	44 (55.7)	42 (55.3)	41 (54.7)
	Stair walking (as tolerated)	3 (3.8)	2 (2.6)	2 (2.7)
Walking program	Walking (30 minutes, at usual pace and with usual walking aid)	66 (83.5)	68 (89.5)	66 (88.0)

[a] Values are number (%) of participants.
[b] Ankle cuff weights were used to provide resistance to the muscles.

participant's baseline assessment results in order to tailor an exercise program targeting the participant's balance and other physical dysfunction identified by the assessment. The first home visit occurred within 1 week following the baseline assessment (for the home exercise prescription), and the same physical therapist returned 4 weeks and 8 weeks after that to make progressive adjustments to the exercise program and to monitor and support ongoing exercise adherence. This exercise program was based on the Otago Exercise Program (supplied by the Accident Compensation Corporation, New Zealand), which has been shown to be effective in improving balance performance and reducing falls in older people at increased fall risk.[23–26] The Otago Exercise Program is a home-based balance and strength retraining and graduated walking program. Details of the program are available on the supplier's Web site (http://www.acc.co.nz). As study participants only had mild levels of balance impairment, additional exercises were selected from the Visual Health Information Balance and Vestibular Exercise Kit (supplied by Health Promotion Resources, Australia, http://www.hprresources.com.au) if the physical therapist considered more challenging exercises were required.

The prescribed exercise program consisted of general warm-up exercises, several balance and strength exercises (see Tab. 1 for a list of the most commonly prescribed exercises), and a tailored walking program. The selection of exercises and number of prescribed exercises depended on assessment findings, areas and levels of impairments,

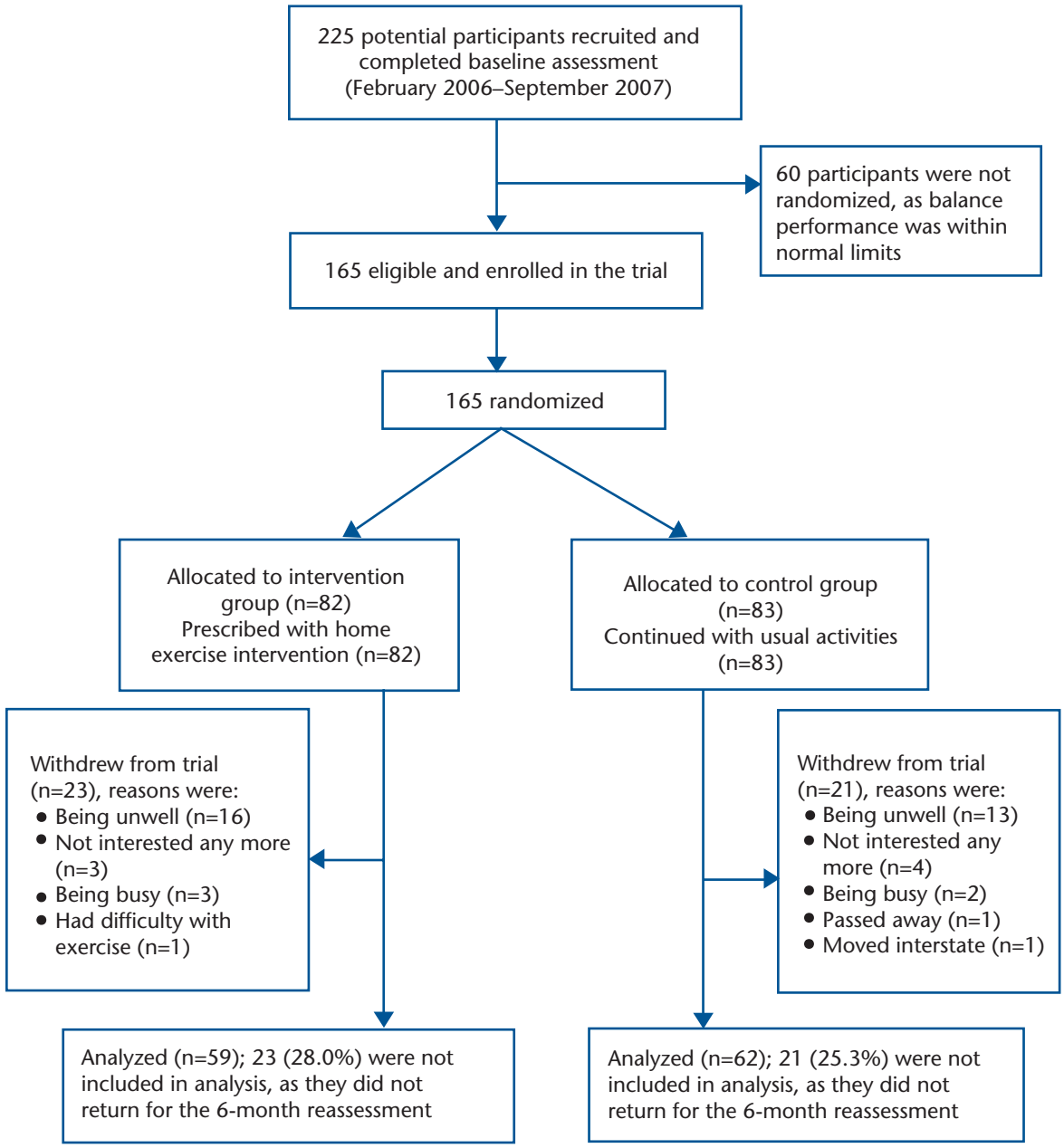

Figure.
Flow of participants through the trial.

safety, and endurance. An exercise manual with pictures and descriptions of selected exercises was provided to each intervention group participant to facilitate exercising. Most participants received 5 to 8 exercises, which usually took approximately 20 minutes to perform, and a graduated walking program aiming for at least 30 minutes per day. Participants were encouraged to perform their prescribed exercises 5 times per week for 6 months. All exercises were performed without upper-limb support. Ankle weights were provided free of charge. Exercise diaries were provided to participants to record the exercises performed.

Safety during standing balance and strengthening exercises was maximized by having the exercises performed in a "boxed-in" area (eg, bench or chair on each side and wall 15–25 cm behind the participants, to be used only for the participants to steady themselves).

Table 2.
Characteristics of Participants in the Intervention (Home Exercise Program) Group and the Control (Usual Activity) Group at Entry Into Trial

Characteristic	Intervention Group (n=82)	Control Group (n=83)
Age (y), $\bar{X}$ (SD)	81.0 (5.9)	80.1 (6.4)
Male, n (%)	45 (54.9)	47 (56.6)
Living with a spouse, n (%)	41 (50.0)	38 (45.8)
Receiving home help, n (%)[a]	30 (36.6)	23 (27.7)
Being a veteran or war widow, n (%)[b]	65 (79.3)	60 (72.3)
Had a fall in previous 12 months, n (%)	31 (37.8)	33 (39.8)
Using a walking stick, n (%)	20 (24.4)	19 (22.9)
No. of medical conditions, median (25th and 75th centiles)	4 (2–6)	4 (3–5)
No. of prescribed medications, median (25th and 75th centiles)	3 (2–6)	4 (2–6)
Height (cm), $\bar{X}$ (SD)	163.8 (9.5)	165.2 (8.0)
Weight (kg), $\bar{X}$ (SD)	70.3 (11.1)	71.2 (12.1)

[a] A basic range of support services such as house cleaning, washing, and meals on wheels, principally provided by the Home and Community Care Program.
[b] Initially, the project targeted recruitment through veterans and war widows agencies. At later stages, recruitment was opened up to include all people aged 65 years and older who met other inclusion criteria.

Participants in the control group were provided with a fall prevention information booklet[50] describing fall risk factors and strategies to minimize falls. Control group participants continued with their usual activities during the 6-month follow-up period.

Data Analysis

Data were analyzed using STATA (Intercooled 9.0, StataCorp LP, College Station, Texas). Baseline demographic and clinical characteristics were summarized as mean (SD), median, and interquartile range or n (%) for each assigned group. Means and standard deviations were reported for variables that were normally distributed, and medians and interquartile ranges were reported for skewed variables. For categorical data, frequency (numbers and percentages) was reported. Analyses of covariance, a special type of multiple linear regression analysis, were used to estimate between-group differences on postintervention outcome measures while adjusting for baseline scores. To reduce the risk of type I error associated with multiple comparisons for the range of balance and related measures used, a Bonferroni adjusted critical *P* value of .0024 (.05/21) was used. Effect sizes (mean change/SD) were calculated for the intervention group for measures that changed significantly with the intervention.

Role of the Funding Source

The study was funded by the Australian Government Department of Veterans' Affairs, which had no role in project implementation, analysis, interpretation, or manuscript writing.

Results

Over a 19-month period, 225 potential participants were recruited for baseline assessment. According to their baseline assessment results, 60 participants were identified as having balance performance within normal limits for their age. Of the remaining 165 study participants with identified mild balance dysfunction, 82 were randomly assigned to the intervention group and 83 were randomly assigned to the control group. Fifty-nine participants (72.0%) in the intervention group and 62 participants (74.7%) in the control group completed the 6-month reassessment. The flow of the participants through the trial is shown in the Figure.

Baseline Measures

Participants' characteristics at entry to the study are reported in Table 2. Participants were aged over 80 years on average, and there were slightly more men than women in both groups. Overall, more than a third of the participants had experienced a fall in the previous 12 months, and less than a quarter reported using a walking stick. The most common medical conditions reported were arthritis (56.9%) and hypertension (54.7%). The distribution of characteristics was similar between the 2 groups. Table 3 summarizes the 2 groups' performance on outcome measures. Participants performed at a similar level at baseline across the 2 groups. Means and standard deviations were reported, as all outcome data were normally distributed.

Withdrawal

Forty-four participants (26.6%)—23 (28.0%) in the intervention group and 21 (25.3%) in the control group—withdrew from the trial. Reasons for not returning for the 6-month reassessment were mostly related to illness (other reasons are detailed in the Figure). There were no significant differences between participants who completed the trial and those who withdrew, although participants who dropped out had slightly more medical conditions and more prescribed medications on average. Table 4 compares the participants' balance performance at baseline, and there were no significant differences on most of the balance-related measures, except that participants who withdrew

Table 3.
Baseline Performance on Main Outcome Measures in the Intervention (Home Exercise Program) Group and the Control (Usual Activity) Group[a]

Outcome Measures	Intervention Group (n=82)	Control Group (n=83)
Laboratory measures		
MCTSIB, mean COG sway velocity composite score (°/s)[b]	1.75 (0.55)	1.68 (0.54)
LOS, reaction time composite score (s)[b]	0.92 (0.24)	0.94 (0.27)
LOS, movement velocity composite score (°/s)	2.90 (1.10)	3.00 (1.19)
LOS, maximum excursion composite score (% LOS)	71.48 (15.17)	72.43 (13.48)
RWS, on-axis velocity (front/back) composite score (°/s)	2.46 (0.75)	2.51 (0.69)
RWS, direction control (front/back) composite score (%)	71.13 (10.50)	70.80 (10.71)
WA, step width (cm)[b]	17.51 (3.95)	17.07 (4.36)
SQT, turn time worse (s)[b]	1.65 (0.89)	1.64 (0.56)
SQT, turn sway, worse (°)[b]	35.05 (12.76)	35.43 (10.45)
STS, body weight rising index (%)	17.22 (5.70)	16.99 (6.41)
STS, COG sway velocity (°/s)	4.72 (1.36)	4.83 (1.16)
Clinical measures		
FRT (cm)	26.01 (5.33)	26.84 (5.49)
Step Test, worse side (steps/15 s)	13.57 (3.74)	14.37 (3.58)
Five-Times Sit-to-Stand Test (s)[b]	11.20 (4.34)	10.65 (3.30)
Quadriceps muscle strength, worse (kg/kg)[c]	0.195 (0.073)	0.200 (0.067)
Hip abductor muscle strength, worse (kg/kg)[c]	0.143 (0.048)	0.156 (0.046)
Dorsiflexor muscle strength, worse (kg/kg)[c]	0.143 (0.041)	0.146 (0.037)
Walking speed (m/min)	60.81 (14.95)	64.34 (12.97)
Other measures		
HAP–AAS	61.34 (11.88)	61.88 (12.59)
MFES score	9.14 (1.36)	9.17 (1.09)
AQoL score[b]	24.80 (4.79)	25.34 (4.76)

[a] Values are mean (SD). MCTSIB=modified Clinical Test of Sensory Interaction on Balance, COG=center of gravity, LOS=limits of stability, RWS=rhythmic weight shift, WA=walk across test, SQT=step quick turn test, worse=worse leg score when a measure is assessed bilaterally, STS=sit-to-stand maneuver, FRT=Functional Reach Test, HAP–AAS=Human Activity Profile–Adjusted Activity Score, MFES=Modified Falls Efficacy Scale, AQoL=Assessment of Quality of Life.
[b] Smaller score represents better performance.
[c] The measured muscle strength (in kilograms) divided by body weight (in kilograms).

from the trial had significantly worse scores at baseline on one clinical outcome measure (Step Test, worse side) and one laboratory outcome measure (LOS maximum excursion composite score).

Adherence to the Intervention

Participants in the intervention group were asked to keep a daily record of exercises they performed using an exercise log sheet. Of the 59 intervention group participants who attended the 6-month reassessment, 26 (44.1%) completed the exercise program 5 or more times per week, which was considered full adherence, and 23 participants (39.0%) exercised 3 or 4 times per week. Only 8 participants (13.6%) reported exercising less than twice a week on average. No adverse events or side effects associated with the exercise program were reported by the intervention group participants.

Six-Month Reassessment

Table 5 compares participants' performance at the 6-month reassessment between the 2 groups, adjusting for baseline scores. Significant improvements were found in the intervention group relative to the control group on the following measures: step width (walk across test on the NeuroCom force platform), FRT, Step Test (worse leg), hip abductor muscle strength (worse side), and activity level (HAP, AAS). Effect sizes (mean change/SD) were

Table 4.
Balance Performance (Baseline) of Participants Who Completed the Trial and Those Who Withdrew Before Trial Completion[a]

Outcome Measures	Participants Who Completed the Trial (n=121)	Participants Who Withdrew (total, n=44)	Intervention Group Participants Who Withdrew (n=23)	Control Group Participants Who Withdrew (n=21)	*P*
Laboratory measures					
MCTSIB, mean COG sway velocity composite score (°/s)[b]	1.68 (0.54)	1.80 (0.56)	1.72 (0.51)	1.89 (0.60)	.22
LOS, reaction time composite score (s)[b]	0.93 (0.24)	0.94 (0.30)	0.91 (0.26)	0.97 (0.34)	.74
LOS, movement velocity composite score (°/s)	3.00 (1.09)	2.81 (1.28)	2.76 (1.28)	2.87 (1.31)	.38
LOS, maximum excursion composite score (% LOS)	73.44 (13.49)	67.78 (15.78)	69.55 (18.51)	66.10 (12.91)	.03[c]
RWS on-axis velocity (front/back) composite score (°/s)	2.49 (0.71)	2.47 (0.74)	2.42 (0.86)	2.52 (0.59)	.84
RWS, direction control (front/back) composite score (%)	71.81 (10.31)	68.81 (11.05)	69.17 (11.75)	68.40 (10.48)	.12
WA, step width (cm)[b]	17.29 (4.18)	17.28 (4.12)	17.72 (3.40)	16.78 (4.87)	.99
SQT, turn time, worse (s)[b]	1.64 (0.81)	1.66 (0.53)	1.61 (0.52)	1.73 (0.55)	.85
SQT, turn sway, worse (°)[b]	35.39 (11.65)	34.83 (11.66)	35.31 (12.07)	34.30 (11.46)	.78
STS, body weight rising index (%)	17.91 (6.41)	16.80 (5.58)	17.56 (5.73)	16.00 (5.48)	.51
STS, COG sway velocity (°/s)[b]	4.72 (1.27)	4.95 (1.23)	4.83 (1.19)	5.09 (1.28)	.34
Clinical measures					
FRT (cm)	26.67 (5.30)	25.76 (5.70)	27.33 (4.46)	24.05 (6.48)	.34
Step Test, worst (steps/15 s)	14.32 (3.70)	13.02 (3.48)	13.09 (4.21)	12.95 (2.56)	.04[c]
Five-Times Sit-to-Stand Test (s)[b]	10.75 (3.60)	11.45 (4.54)	12.30 (5.72)	10.47 (2.38)	.32
Quadriceps muscle strength, worse (kg/kg)[d]	0.20 (0.07)	0.20 (0.08)	0.20 (0.09)	0.20 (0.08)	.61
Hip abductor muscle strength, worse (kg/kg)[d]	0.15 (0.05)	0.14 (0.04)	0.14 (0.04)	0.14 (0.04)	.13
Dorsiflexor muscle strength, worse (kg/kg)[d]	0.15 (0.04)	0.14 (0.04)	0.14 (0.04)	0.14 (0.04)	.21
Walking speed (m/min)	63.47 (14.71)	60.30 (11.86)	59.72 (12.84)	60.97 (10.91)	.21
Other measures					
HAP–AAS	62.16 (12.52)	60.11 (11.29)	60.26 (11.58)	59.95 (11.24)	.34
MFES score	9.18 (1.26)	9.10 (1.16)	9.06 (1.29)	9.15 (1.04)	.72
AQoL score[b]	24.89 (4.61)	25.57 (5.20)	24.91 (4.90)	26.29 (5.54)	.42

[a] Values are mean (SD); *P* values indicate differences between participants who completed the trial and those who withdrew from the trial.
MCTSIB=modified Clinical Test of Sensory Interaction on Balance, COG=center of gravity, LOS=limits of stability, RWS=rhythmic weight shift, WA=walk across test, SQT=step quick turn test, worse=worse leg score when a measure is assessed bilaterally, STS=sit-to-stand maneuver, FRT=Functional Reach Test, HAP–AAS=Human Activity Profile–Adjusted Activity Score, MFES=Modified Falls Efficacy Scale, AQoL=Assessment of Quality of Life.
[b] Smaller score represents better performance.
[c] Significant difference ($P<.05$) from 2-sample *t* test with equal variances.
[d] The measured muscle strength (in kilograms) divided by body weight (in kilograms).

calculated for the intervention group for measures that changed significantly with the intervention. Effect sizes ranged from 0.2 (small effect) for hip abductor strength to 0.56 (moderate effect size) for the FRT, with most of the measures having effect sizes in the range of 0.3 to 0.5. Nonsignificant trends for improvements were observed on most of the other measures in the intervention group relative to the control group. Of the 59 intervention group participants who completed the exercise program, 14 (23.7%) improved their balance performance to the point where they were classified as not having mild balance dysfunction, using the same classification system to identify mild balance dysfunction used at baseline (normative performance on the 3 clinical tests and no more than 3 abnormal scores on the 46 NeuroCom measures), compared with 3 (4.8%) in the control group ($P=.003$) (data not shown in Tab. 5).

Falls data during the 6-month follow-up period were available for all 121 participants who completed the trial based on self-report. Although fewer intervention group participants (12 out of 59, 20%) fell in the 6 months compared with the control group participants (18 out of 62, 29%) (relative risk=0.70, 95% CI=

Table 5.
Balance Performance on Outcome Measures Before and After Intervention of Intervention Group and Control Group Participants Who Completed the Trial[a]

Outcome Measures	Intervention Group (n=59)		Control Group (n=62)		Mean Difference Between Groups (95% CI)	*P*
	Baseline	Follow-up	Baseline	Follow-up		
Laboratory measures						
MCTSIB, mean COG sway velocity composite score (°/s)[b]	1.76 (0.58)	1.50 (0.56)	1.61 (0.49)	1.51 (0.52)	−0.12 (−0.27 to 0.33)	.12
LOS, reaction time composite score (s)[b]	0.93 (0.24)	1.02 (0.33)	0.92 (0.24)	0.95 (0.33)	0.07 (−0.03 to 0.18)	.18
LOS, movement velocity composite score (°/s)	2.95 (1.03)	3.41 (1.27)	3.05 (1.15)	3.25 (1.24)	0.16 (−0.22 to 0.53)	.41
LOS, maximum excursion composite score (% LOS)	72.16 (13.93)	75.75 (15.17)	74.68 (13.06)	77.50 (15.74)	0.77 (−4.23 to 2.69)	.66
RWS, on-axis velocity (front/back) composite score (°/s)	2.48 (0.70)	2.79 (0.84)	2.51 (0.72)	2.72 (0.81)	0.13 (−0.12 to 0.38)	.31
RWS, direction control (front/back) composite score (%)	71.95 (9.94)	69.09 (10.37)	71.67 (10.76)	68.21 (13.64)	−0.02 (−3.98 to 3.94)	.99
WA, step width (cm)[b]	17.41 (4.18)	16.08 (4.07)	17.17 (4.21)	17.96 (3.61)	−2.17 (−3.11 to −1.23)	<.001[c]
SQT, turn time, worse (s)[b]	2.07 (0.99)	1.79 (0.70)	2.02 (0.65)	1.92 (0.83)	−0.15 (−0.40 to 0.10)	.24
SQT, turn sway, worse (°)[b]	43.73 (13.72)	38.16 (10.95)	45.46 (13.15)	40.53 (12.51)	−2.01 (−6.17 to 2.14)	.34
STS, body weight rising index (%)	16.98 (5.75)	18.96 (7.47)	18.80 (11.87)	18.46 (6.09)	1.68 (−0.83 to 4.19)	.19
STS, COG sway velocity (°/s)[b]	4.69 (1.43)	4.81 (1.28)	4.74 (1.12)	4.93 (0.96)	−0.13 (−0.43 to 0.17)	.39
Clinical measures						
FRT (cm)	25.49 (5.58)	28.39 (4.86)	27.78 (4.80)	26.87 (4.30)	2.95 (1.75 to 4.15)	<.001[c]
Step Test, worst (steps/15 s)	13.76 (3.56)	15.54 (3.99)	14.58 (3.77)	14.41 (3.77)	2.10 (1.17 to 3.02)	<.001[c]
Five-Times Sit-to-Stand Test (s)[b]	10.78 (3.65)	9.76 (2.37)	10.72 (3.57)	10.93 (3.54)	−1.08 (−1.83 to −0.33)	.01
Quadriceps muscle strength, worse (kg/kg)[d]	0.19 (0.07)	0.22 (0.07)	0.20 (0.06)	0.20 (0.07)	0.03 (0.01 to 0.05)	.01
Hip abductor muscle strength, worse (kg/kg)[d]	0.15 (0.05)	0.16 (0.05)	0.16 (0.05)	0.15 (0.05)	0.02 (0.01 to 0.03)	.001[c]
Dorsiflexor muscle strength, worse (kg/kg)[d]	0.15 (0.04)	0.16 (0.04)	0.15 (0.04)	0.16 (0.04)	0.008 (−0.01 to 0.01)	.89
Walking speed (m/min)	61.26 (15.84)	61.39 (13.33)	65.43 (13.46)	62.15 (13.91)	2.07 (−1.49 to 5.63)	.25
Other measures						
HAP–AAS	61.76 (12.06)	66.24 (10.43)	62.54 (13.04)	62.31 (12.40)	4.57 (1.84 to 7.29)	.001[c]
MFES score	9.18 (1.40)	9.23 (1.17)	9.18 (1.12)	9.11 (1.41)	0.14 (−0.21 to 0.48)	.43
AQoL score[b]	24.76 (4.79)	23.37 (4.10)	25.02 (4.46)	24.55 (5.21)	−1.01 (−2.17 to 0.15)	.09

[a] Values are mean (SD), mean differences (95% confidence interval [CI]), and *P* value between intervention group and control group at follow-up assessment adjusting for baseline scores. MCTSIB=modified Clinical Test of Sensory Interaction on Balance, COG=center of gravity, LOS=limits of stability, RWS=rhythmic weight shift, WA=walk across test, SQT=step quick turn test, worse=worse leg score when a measure is assessed bilaterally, STS=sit-to-stand maneuver, FRT=Functional Reach Test, HAP–AAS=Human Activity Profile–Adjusted Activity Score, MFES=Modified Falls Efficacy Scale, AQoL=Assessment of Quality of Life.
[b] Smaller score represents better performance.
[c] Significant difference (Bonferroni adjusted $P<.0024$).
[d] The measured muscle strength (in kilograms) divided by body weight (in kilograms).

0.37 to 1.33) and there were fewer multiple fallers in the intervention group (2 out of 59, 3.3%) than in the control group (8 out of 62, 12.9%), these results were not statistically significant.

Discussion

There is previous evidence that exercise can improve a range of balance-related outcomes and reduce falls in older people.[9] However, the majority of previous research has targeted older people with increased risk of falls[17,51] or, in some cases, unscreened community-dwelling older people.[13,52] The results of this study add to the existing research by targeting a well-screened group of older people with identified mild balance dysfunction. From a prevention or health promotion perspective, this is an important group to

target, as many older people do not seek health professional advice until serious injury has resulted from a fall.[53] Assessment and intervention at a stage when balance dysfunction is mild may prevent this group from progressing to having a serious fall, which is when older people more commonly seek professional advice. In addition to potential benefits in preventing falls, improved balance and related performance also are likely to have a positive impact on older people's function and independence.[54] Importantly, one of the significant outcomes of this targeted exercise program was an increased level of physical activity, which can lead to a range of other health benefits in older people.[55,56]

This study demonstrated that a personalized, home-based exercise program based in part on the Otago Exercise Program, which has been shown to be effective in improving balance, strength, and function,[8,23] can improve mild balance dysfunction in older people. Although previous studies have demonstrated improved physical function or balance performance in frail older people[14,15] or "healthy older adults,"[12,13] the current study provides new insights that this well-screened group of older adults with mild balance dysfunction can benefit from this type of exercise program. To our knowledge, this study is the first to investigate the effectiveness of a home exercise intervention in well-screened older people with mild balance dysfunction.

In this study, there were fewer fallers and fewer multiple fallers in the intervention group than in the control group, but the differences were not statistically significant. However, these preliminary findings are not conclusive, as the study was not powered to evaluate falls. Additionally, falls data were collected via retrospective recall. Future studies aiming to evaluate the effectiveness of exercise programs in reducing falls in this population are likely to require larger sample sizes based on an appropriate power analysis.

The effect of the intervention was examined on multiple outcome measures, including simple clinical measures and computerized force platform measures. The results showed that the intervention group achieved significant improvements on most of the clinical measures after 6 months, with several of these differences approaching a moderate effect size, suggesting meaningful clinical change. For instance, at the 6-month follow-up assessment, participants in the intervention group scored 2.95 cm better on the FRT compared with participants in the control group after adjusting for baseline difference between groups (details for other tests are shown in Tab. 5).

These findings confirmed the study hypothesis that older people with a mild level of balance dysfunction can benefit from a personalized exercise program, as previous studies have demonstrated in other populations.[22–26] Although not statistically significant, the intervention group also demonstrated a mean improvement of 3.4% to 14.8% on most of the laboratory measures, whereas the control group generally demonstrated a deterioration (2.7%–4.7%) or minimal improvement (1.8%–7.9%) in performing the functional tasks on the force platform. It is not clear why the laboratory measures did not demonstrate significant differences, as was observed with the majority of the clinical measures. A possible explanation may relate to the specificity of training and to the fact that the exercise program may have addressed movement limitations similar to those assessed in the clinical tests (stepping, reaching, STS maneuver) more than those of the laboratory measures. Further research as to the optimal mix of exercises for specific identified balance deficits is warranted to maximize potential outcomes.

The findings from this study suggest that an approach to early identification of mild balance dysfunction and targeted exercise interventions may have a range of health benefits in older people. However, for this approach to be implemented widely in the community setting, future research needs to evaluate the utility of a clinical assessment battery in isolation (without the use of force platform measures), given the limited availability of force platforms in community settings. Some observations from our data suggest that one or more of the clinical tests (eg, Step Test) used in this study may be suitable to be used individually or in combination to detect early signs of balance dysfunction in older people. Also of importance, our research demonstrated that clinical measures such as the FRT, Step Test, and Five-Time Sit-to-Stand Test appear to be useful outcome measures in quantifying intervention effectiveness. Although Vereeck et al[57] previously reported that simple clinical measures might suffer from ceiling effects when used in samples of older people with a high level of functioning, this did not appear to be a problem in our study. For instance, study participants (n=165) had an average score of 26 cm on the FRT, with the scores being normally distributed (skewness=0.021, kurtosis=−0.230, P=.860). Thirty-nine participants (23.6%) scored between 25 and 27 cm, and only 5 participants (3.0%) scored in the highest range (40 cm or above).

To date, there have been few published studies examining older people's mild balance dysfunction. The current study explored screening mild levels of balance impairment in older people by using combined clin-

ical and laboratory measures. As this approach has not been used previously, specific criteria were developed for classifying performance as "within normal limits" or "mild balance impairment" in this study, using a combination of clinical and laboratory balance-related measures.

The 165 participants who were classified as having mild balance dysfunction had a median number of 6 NeuroCom scores that were outside the normative range (25%–75% percentiles: 4–10). This is a relatively small number out of the total 46 parameters derived from NeuroCom measures. A further indication that the classification process did identify participants with mild balance impairments is gained by comparing the baseline scores on 2 of the clinical balance measures in our study with scores for a well-screened sample of older people who were healthy[58] and a high fall risk group (from a falls clinic).[59] Scores for the Step Test and the FRT in our sample (approximately 14 steps/15 seconds and 27 cm, respectively) were slightly lower than those reported for the well-screened sample of older people who were healthy (approximately 16 steps/15 seconds and 31 cm, respectively) and were well above scores reported for the falls clinic sample (approximately 8 steps/15 seconds and 23 cm, respectively).

Furthermore, although not an aim of the study, we explored *post hoc* the accuracy of this classification system in identifying fallers from the control group of participants classified as having mild balance impairment (62 with complete falls data for the 6-month follow-up period, of whom 18 fell) and the 60 potential participants who were recruited but were classified as being within the normal range of balance performance and thus were not included in the randomized trial (53 had complete 6-month follow-up falls data, of whom 4 fell). Using these data, the classification system correctly classified 18 of the 22 fallers, resulting in a sensitivity of 82%. In combination, the comparisons described above and this *post hoc* sensitivity for classification of fallers analysis provide some support for the classification system to identify mild balance dysfunction used in this study. Further research is needed to clearly define "mild balance dysfunction," to further validate this classification system, and to determine whether a simplified, more time-efficient testing battery that can be widely used in primary care settings will be as accurate in classifying mild balance dysfunction.

This trial was carried out according to the CONSORT statement.[60] A separate researcher performed the randomization, and all assessors involved in data collection were blinded to group allocation. The study also had limitations. The relatively high rate of loss to follow-up (26.6%) is slightly higher than for similar studies and was a limitation of this study. However, the number of participants who dropped out was similar for the 2 groups, and those who dropped out did not differ from those who remained in the study on the majority of the baseline measures, nor were there significant differences in the intervention and control groups for baseline measures in those who dropped out. An intention-to-treat analysis of participants with data available at follow-up was performed and reported.[60] A further limitation was that the participants were volunteers who responded to advertisements or project promotion, which may limit the generalizability to the wider population. In addition, participants in the intervention group received 3 home visits by an experienced physical therapist, and such home visits may not always be possible in a real-life (non-research) setting. Therefore, further research is needed to investigate whether this approach can be translated into practice through regular community care centers and whether participant adherence levels can be maintained or improved using this approach.

In conclusion, a personalized, home-based exercise program of balance and strength training significantly improved performance on balance-related measures in older people with mild balance dysfunction. This study provides interesting new data on assessment and exercise interventions for older people with a mild level of balance impairment and confirmed the hypothesis that older people's mild balance dysfunction can improve with a home-based exercise program.

Dr Yang, Dr Hill, Ms Moore, Ms Williams, and Dr Dharmage provided concept/idea/research design. Dr Yang, Dr Hill, Ms Moore, Ms Williams, Ms Borschmann, Dr Simpson, and Dr Dharmage provided writing and consultation (including review of manuscript before submission). Dr Yang, Dr Hill, Ms Moore, Ms Williams, and Ms Dowson provided data collection. Dr Yang, Dr Hill, Ms Borschmann, Dr Simpson, and Dr Dharmage provided data analysis. Dr Yang, Dr Hill, Ms Moore, and Ms Williams provided project management. Dr Hill, Ms Moore, and Ms Williams provided fund procurement. Dr Yang, Dr Hill, and Ms Moore recruited participants. Dr Hill provided facilities/equipment and institutional liaisons. Dr Hill, Ms Williams, and Ms Dowson provided clerical support. The authors thank all participants for volunteering for the study.

The project was approved by the Australian Government Department of Veterans' Affairs Ethics Committee.

The research team acknowledges the Australian Government Department of Veterans' Affairs for providing the research funding.

Australian New Zealand Clinical Trials Registry (ANZCTR) registry number: ACTRN12607000525482.

DOI: 10.2522/ptj.20100289

References

1 Winter D. Human balance and posture control during standing and walking. *Gait Posture.* 1995;3:193–214.

2 Daubney ME, Culham EG. Lower-extremity muscle force and balance performance in adults aged 65 years and older. *Phys Ther.* 1999;79:1177–1185.

3 Berg K. Balance and its measure in the elderly: a review. *Physiother Can.* 1989; 41:240–246.

4 Stelmach GE. Physical activity and ageing: sensory and perceptual processing. In: Bouchard C, Shepard RJ, Stephens T, eds. *Physical Fitness and Health.* Champaign, IL: Human Kinetics; 1994.

5 Campbell AJ, Borrie MJ, Spears GF. Risk-factors for falls in a community-based prospective study of people 70 years and older. *J Gerontol.* 1989;44:M112–M117.

6 Lord SR, Sherrington C, Menz HB, Close JC. *Falls in Older People: Risk Factors and Strategies for Prevention.* 2nd ed. Cambridge, United Kingdom: Cambridge University Press; 2007.

7 Shumway-Cook A, Silver IF, LeMier M, et al. Effectiveness of a community-based multifactorial intervention on falls and fall risk factors in community-living older adults: a randomized, controlled trial. *J Gerontol A Biol Sci Med Sci.* 2007;62: 1420–1427.

8 Edwards N. A home-based, nurse-delivered exercise programme reduced falls and serious injuries in people >/=80 years of age. *Evid Based Nurs.* 2002;5:22.

9 Sherrington C, Whitney JC, Lord SR, et al. Effective exercise for the prevention of falls: a systematic review and meta-analysis. *J Am Geriatr Soc.* 2008;56:2234–2243.

10 Wolf SL, Barnhart HX, Kutner NG, et al. Reducing frailty and falls in older persons—an investigation of Tai Chi and computerized balance training: Atlanta FIC SIT Group, Frailty and Injuries: Cooperative Studies of Intervention Techniques. *J Am Geriatr Soc.* 1996;44:489–497.

11 Chandler JM, Hadley EC. Exercise to improve physiologic and functional performance in old age. *Clin Geriatr Med.* 1996;12:761–784.

12 Johansson G, Jarnlo GB. Balance training in 70-year-old women. *Physiother Theory Pract.* 1991;7:121–125.

13 Paillard T, Lafont C, Costes-Salon MC, et al. Effects of brisk walking on static and dynamic balance, locomotion, body composition, and aerobic capacity in ageing healthy active men. *Int J Sports Med.* 2004;25:539–546.

14 Nelson ME, Layne JE, Bernstein MJ, et al. The effects of multidimensional home-based exercise on functional performance in elderly people. *J Gerontol A Biol Sci Med Sci.* 2004;59:154–160.

15 Krebs DE, Jette AM, Assmann SF. Moderate exercise improves gait stability in disabled elders. *Arch Phys Med Rehabil.* 1998;79: 1489–1495.

16 Sauvage LR Jr, Myklebust BM, Crow-Pan J, et al. A clinical trial of strengthening and aerobic exercise to improve gait and balance in elderly male nursing home residents. *Am J Phys Med Rehabil.* 1992;71: 333–342.

17 Sihvonen SE, Sipila S, Era PA. Changes in postural balance in frail elderly women during 4-week visual feedback training: a randomized controlled trial. *Gerontology.* 2004;50:87–95.

18 Marigold DS, Eng JJ, Dawson AS, et al. Exercise leads to faster postural reflexes, improved balance and mobility, and fewer falls in older persons with chronic stroke. *J Am Geriatr Soc.* 2005;53:416–423.

19 Langhammer B, Stanghelle JK, Lindmark B. An evaluation of two different exercise regimes during the first year following stroke: a randomised controlled trial. *Physiother Theory Pract.* 2009;25:55–68.

20 Hirsch MA, Toole T, Maitland CG, Rider RA. The effects of balance training and high-intensity resistance training on persons with idiopathic Parkinson's disease. *Arch Phys Med Rehabil.* 2003;84:1109–1117.

21 Skelton D, Dinan S, Campbell M, Rutherford O. Tailored group exercise (Falls Management Exercise–FaME) reduces falls in community-dwelling older frequent fallers (an RCT). *Age Ageing.* 2005;34:636–639.

22 Liu-Ambrose T, Donaldson MG, Ahamed Y, et al. Otago home-based strength and balance retraining improves executive functioning in older fallers: a randomized controlled trial. *J Am Geriatr Soc.* 2008; 56:1821–1830.

23 Campbell AJ, Robertson MC, Gardner MM, et al. Falls prevention over 2 years: a randomized controlled trial in women 80 years and older. *Age Ageing.* 1999;28: 513–518.

24 Campbell AJ, Robertson MC, Gardner MM, et al. Psychotropic medication withdrawal and a home-based exercise program to prevent falls: a randomized, controlled trial. *J Am Geriatr Soc.* 1999;47:850–853.

25 Robertson MC, Devlin N, Gardner MM, Campbell AJ. Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls; 1: randomized controlled trial. *BMJ.* 2001;322: 697–701.

26 Robertson MC, Gardner MM, Devlin N, et al. Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls; 2: controlled trial in multiple centres. *BMJ.* 2001;322: 701–704.

27 Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society. Summary of the updated American Geriatrics Society/British Geriatrics Society clinical practice guideline for prevention of falls in older persons. *J Am Geriatr Soc.* 2011;59: 148–157.

28 Srygley JM, Herman T, Giladi N, Hausdorff JM. Self-report of missteps in older adults: a valid proxy of fall risk? *Arch Phys Med Rehabil.* 2009;90:786–792.

29 Voermans NC, Snijders AH, Schoon Y, Bloem BR. Why old people fall (and how to stop them). *Pract Neurol.* 2007;7: 158–171.

30 Muir SW, Berg K, Chesworth B, et al. Balance impairment as a risk factor for falls in community-dwelling older adults who are high functioning: a prospective study. *Phys Ther.* 2010;90:338–347.

31 Curb JD, Ceria-Ulep CD, Rodriguez BL, et al. Performance-based measures of physical function for high-function populations. *J Am Geriatr Soc.* 2006;54: 737–742.

32 Herman CR, Gill HK, Eng J, Fajardo LL. Screening for preclinical disease: test and disease characteristics. *AJR Am J Roentgenol.* 2002;179:825–831.

33 Duncan PW, Weiner DK, Chandler J, Studenski S. Functional reach: a new clinical measure of balance. *J Gerontol.* 1990; 45:M192–M197.

34 Hill K, Bernhardt J, McGann AM, et al. A new test of dynamic standing balance for stroke patients: reliability, validity, and comparison with healthy elderly. *Physiother Can.* 1996;48:257–262.

35 Csuka M, McCarty DJ. Simple method for measurement of lower extremity muscle strength. *Am J Med.* 1985;78:77–81.

36 Bernhardt J, Hill K. We only treat what it occurs to us to assess: the importance of knowledge based assessment. In: Refshauge K, Ada L, Ellis E, eds. *Science-Based Rehabilitation: Theories Into Practice.* Oxford, United Kingdom: Elsevier Publishers; 2005.

37 Condron J, Hill KD. Reliability and validity of a dual task force platform assessment of balance performance: effect of age, balance impairment, and cognitive task. *J Am Geriatr Soc.* 2002;50:157–162.

38 Lord SR, Murray SM, Chapman K, et al. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *J Gerontol A Biol Sci Med Sci.* 2002; 57:M539–M543.

39 Ottenbacher KJ, Branch LG, Ray L, et al. The reliability of upper- and lower-extremity strength testing in a community survey of older adults. *Arch Phys Med Rehabil.* 2002;83:1423–1427.

40 El Haber N, Erbas B, Hill KD, Wark JD. Relationship between age and measures of balance, strength and gait: linear and non-linear analyses. *Clin Sci (Lond).* 2008;114: 719–727.

41 Hageman PA, Blanke DJ. Comparison of gait of young women and elderly women. *Phys Ther.* 1986;66:1382–1387.

42 Lam HS, Lau FW, Chan GK, Sykes K. The validity and reliability of a 6-metre timed walk for the functional assessment of patients with stroke. *Physiother Theory Pract.* 2010;26:251–255.

43 Naylor ME, Romani WA. Test-retest reliability of three dynamic tests obtained from active females using the NeuroCom Balance Master. *J Sport Rehabil.* 2006;15: 326–337.

44 Brouwer B, Culham EG, Liston RA, Grant T. Normal variability of postural measures: implications for the reliability of relative balance performance outcomes. *Scand J Rehabil Med.* 1998;30:131–137.

45 Vrantsidis F, Hill KD, Moore K, et al. Getting grounded gracefully: effectiveness and acceptability of Feldenkrais in improving balance. *J Aging Phys Act.* 2009;17:57–76.

46 Fix A, Daughton D. *Human Activity Profile Professional Manual.* Odessa, FL: Pychological Assessment Resources Inc; 1988.

47 Hawthorne G, Richardson J, Osborne R. The Assessment of Quality of Life (AQoL) instrument: a psychometric measure of health-related quality of life. *Qual Life Res.* 1999;8:209–224.

48 Hill KD, Schwarz JA, Kalogeropoulos AJ, Gibson SJ. Fear of falling revisited. *Arch Phys Med Rehabil.* 1996;77:1025–1029.

49 Islam MM, Nasu E, Rogers ME, et al. Effects of combined sensory and muscular training on balance in Japanese older adults. *Prev Med.* 2004;39:1148–1155.

50 *Enjoy the Best Years of Your Life: A Guide to Preventing Falls*. Victoria, Australia: Peninsula Health Falls Prevention Service; 2009.

51 Lord SR, Castell S, Corcoran J, et al. The effect of group exercise on physical functioning and falls in frail older people living in retirement villages: a randomized, controlled trial. *J Am Geriatr Soc.* 2003;51:1685–1692.

52 Shigematsu R, Okura T, Nakagaichi M, et al. Square-stepping exercise and fall risk factors in older adults: a single-blind, randomized controlled trial. *J Gerontol A Biol Sci Med Sci.* 2008;63:76–82.

53 Managing Innovation Marketing Consultancy Network Pty Ltd. *National Falls Prevention for Older People Initiative "Step Out With Confidence": A Study Into the Information Needs and Perceptions of Older Australians Concerning Falls and Their Prevention*. Prepared for the Commonwealth Department of Health and Aged Care. Canberra, Australia: Commonwealth of Australia (AusInfo); 2000.

54 Wolfson L, Whipple R, Judge J, et al. Training balance and strength in the elderly to improve function. *J Am Geriatr Soc.* 1993;41:341–343.

55 Peterson MJ, Giuliani C, Morey MC, et al. Physical activity as a preventative factor for frailty: the Health, Aging, and Body Composition Study. *J Gerontol A Biol Sci Med Sci.* 2009;64:61–68.

56 King AC, Rejeski WJ, Buchner DM. Physical activity interventions targeting older adults: a critical review and recommendations. *Am J Prev Med.* 1998;15:316–333.

57 Vereeck L, Wuyts F, Truijen S, Van De Heyning P. Clinical assessment of balance: normative data, and gender and age effects. *Inl J Audiol.* 2008;47:67–75.

58 Hill K, Schwarz J, Flicker L, Carroll S. Falls among healthy, community-dwelling, older women: a prospective study of frequency, circumstances, consequences and prediction accuracy. *Aust N Z J Public Health*. 1999;23:41–48.

59 Hill K. *Studies of Balance in Older People* [PhD thesis]. Sydney, Australia: The University of Melbourne; 1998.

60 Altman DG, Schulz KF, Moher D, et al. The revised CONSORT statement for reporting randomized trials: explanation and elaboration. *Ann Intern Med.* 2001;134:663–694.