

Resistance and Agility Training Reduce Fall Risk in Women Aged 75 to 85 with Low Bone Mass: A 6-Month Randomized, Controlled Trial*

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OBJECTIVES: To compare the effectiveness of group resistance and agility-training programs in reducing fall risk in community-dwelling older women with low bone mass.

DESIGN: A randomized, controlled, single-blind 25-week prospective study with assessments at baseline, midpoint, and trial completion.

SETTING: Community center.

PARTICIPANTS: Community-dwelling women aged 75 to 85 with low bone mass.

INTERVENTION: Participants were randomly assigned to one of three groups: resistance training (n = 32), agility training (n = 34), and stretching (sham) exercises (n = 32). The exercise classes for each study arm were held twice weekly.

MEASUREMENTS: The primary outcome measure was fall risk (derived from weighted scores from tests of postural

sway, reaction time, strength, proprioception, and vision), as measured using a Physiological Profile Assessment (PPA). Secondary outcome measures were ankle dorsiflexion strength, foot reaction time, and Community Balance and Mobility Scale score.

RESULTS: Attendance at the exercise sessions for all three groups was excellent: resistance training (85.4%), agility training (87.3%), and stretching program (78.8%). At the end of the trial, PPA fall-risk scores were reduced by 57.3% and 47.5% in the resistance and agility-training groups, respectively, but by only 20.2% in the stretching group. In the resistance and agility groups, the reduction in fall risk was mediated primarily by improved postural stability, where sway was reduced by 30.6% and 29.2%, respectively. There were no significant differences between the groups for the secondary outcomes measures. Within the resistance-training group, reductions in sway were significantly associated with improved strength, as assessed using increased squat load used in the exercise sessions.

CONCLUSION: These findings support the implementation of community-based resistance and agility-training programs to reduce fall risk in older women with low bone mass. Such programs may have particular public health benefits because it has been shown that this group is at increased risk of falling and sustaining fall-related fractures. *J Am Geriatr Soc* 52:657–665, 2004.

Key words: accidental falls; fall risk; exercise; aged; low bone mass

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Falls are a relatively common event in older people. Approximately 30% of individuals aged 65 and older fall at least once a year, and about half of those do so recurrently. Fall-related injuries and death in older people are a major healthcare problem worldwide, with the numbers continuing to rise.¹ Thus, fall prevention in older people remains a major healthcare priority.

Falls are not random events² and occur, at least in part, because of physiological impairments, such as impaired

balance, muscular weakness, and slowed reaction time.³ Exercise can effectively reduce fall risk factors and falls in older people by ameliorating physiological impairments. For example, one study⁴ demonstrated that a community-based general exercise program improved balance, muscular strength, and reaction time in older women. Furthermore, tai chi quan⁵ and a home-based strength and balance training program⁶ have reduced the incidence of falls in community-dwelling older adults. However, exercise comes in many forms, and further research is needed to delineate the specifics of exercise prescription for optimal fall risk and falls reduction. Defining the components of exercise that are effective in reducing fall risk would provide some insight into the possible underlying mechanisms by which exercise exerts its effect and allow those prescribing exercise to do so more effectively.

Fractures, especially of the hip, are particularly disabling consequences of falling.⁷ One group of individuals at particularly high risk of sustaining fall-related fractures are those with low bone mass. For example, each standard deviation (SD) decrease in femoral neck bone density increases the age-adjusted risk of hip fracture 2.6 times.⁸ Furthermore, older women with osteoporosis may have a greater risk of falling because of greater impairments in balance and muscular strength than in age-matched counterparts without osteoporosis.⁹ Thus, exercise programs aimed at reducing fall risk and falls may be particularly important for older people with low bone mass.

Recently, a randomized, controlled trial was conducted that examined the effectiveness of a general exercise program in reducing fall risk in this population.¹⁰ This study found that low-intensity strength, coordination, and balance exercises were effective in improving strength and balance. The current study built on this work by conducting a 25-week, single-blind, randomized, controlled trial to compare the effectiveness of two types of community-based exercise programs (high-intensity resistance training and agility training) in reducing fall risk in community-dwelling older women with low bone mass.

METHODS

Study Design

A randomized, controlled 25-week prospective study with three measurement periods (baseline, midpoint, and trial completion) was conducted. The assessors were blinded to the participants' assignments.

Participants

All women aged 75 to 85 who were residents of greater Vancouver and in whom osteoporosis or osteopenia had been diagnosed at the British Columbia Women's Hospital and Health Center (defined as a T-score at the total hip or spine at least 1.0 SD below the young normal sex-matched areal bone mineral density (BMD) of the Lunar reference database)¹¹ were identified as potential participants. In addition, the Osteoporosis Society of Canada, British Columbia section, provided a list of individuals with low bone mass who had provided permission to be approached for research studies. Six hundred eighty-three letters of recruitment were mailed to the women identified from these

databases. Local newspaper, radio, and poster advertisements were also used to aid in recruitment. Low bone mass was confirmed in participants recruited in this manner using a dual-energy x-ray absorptiometry BMD scan.

Interested individuals were screened using a standardized telephone interview, which included the revised physical activity readiness questionnaire^{12,13} and were then invited to an information session at which a physician (KMK) assessed all potential participants. Women who were living in care facilities, were of non-Caucasian race, were regularly exercising twice weekly or more, had a history of illness or a condition that would affect balance (e.g., stroke or Parkinson's disease), were unable to safely participate in the exercise program, or had a Mini-Mental State Examination (MMSE)¹⁴ score of 23 or less were excluded. Figure 1 shows the number of participants in the treatment arms at each stage of the study.

The University of British Columbia clinical research ethics board and the research committee of the Children's and Women's Hospital of British Columbia approved the study. All participants gave written informed consent before participating in the study.

Descriptive Variables

Age was measured in years, standing height in centimeters, and mass in kilograms in all participants. General health was assessed using questions from the Canadian Multi-centre Osteoporosis Study questionnaire¹⁵ that relate to current medication use, current supplement use, the presence of medical conditions known to be fall risk factors (such as osteoarthritis), and history of falls. Trained interviewers administered this questionnaire at baseline. All participants also underwent an assessment by a physician to confirm health status, and walking aid use was recorded.

Cognitive state was assessed using the MMSE.¹⁴ Each participant's current level of physical activity was determined at the three measurement periods using the Physical Activities Scale for the Elderly (PASE) questionnaire.^{16,17} Visual acuity, both high and low contrast, was assessed at a test distance of 3 meters.¹⁸ Corrected acuity was determined binocularly and measured in terms of the minimum angle resolvable in minutes of arc. Tactile sensitivity was assessed using a pressure aesthesiometer.¹⁸ Filaments of varying thickness were applied to the center of the lateral malleolus, and measurements are expressed in logarithms of milligrams pressure.

Adherence to the assigned exercise program was recorded for each participant and expressed as the percentage of the 48 classes (maximum number of classes) attended. All 98 participants were asked to keep a fall diary throughout the intervention period.

Primary Outcome Measure

Participants' fall risk was assessed at the three measurement periods using the Physiological Profile Assessment ((PPA) Prince of Wales Medical Research Institute, Randwick, Sydney, NSW, Australia).¹⁸ The PPA is a valid^{19,20} and reliable²¹ tool for assessing fall risk in older people. Based on the performance of five physiological domains (vision, proprioception, strength, reaction time, and balance), the

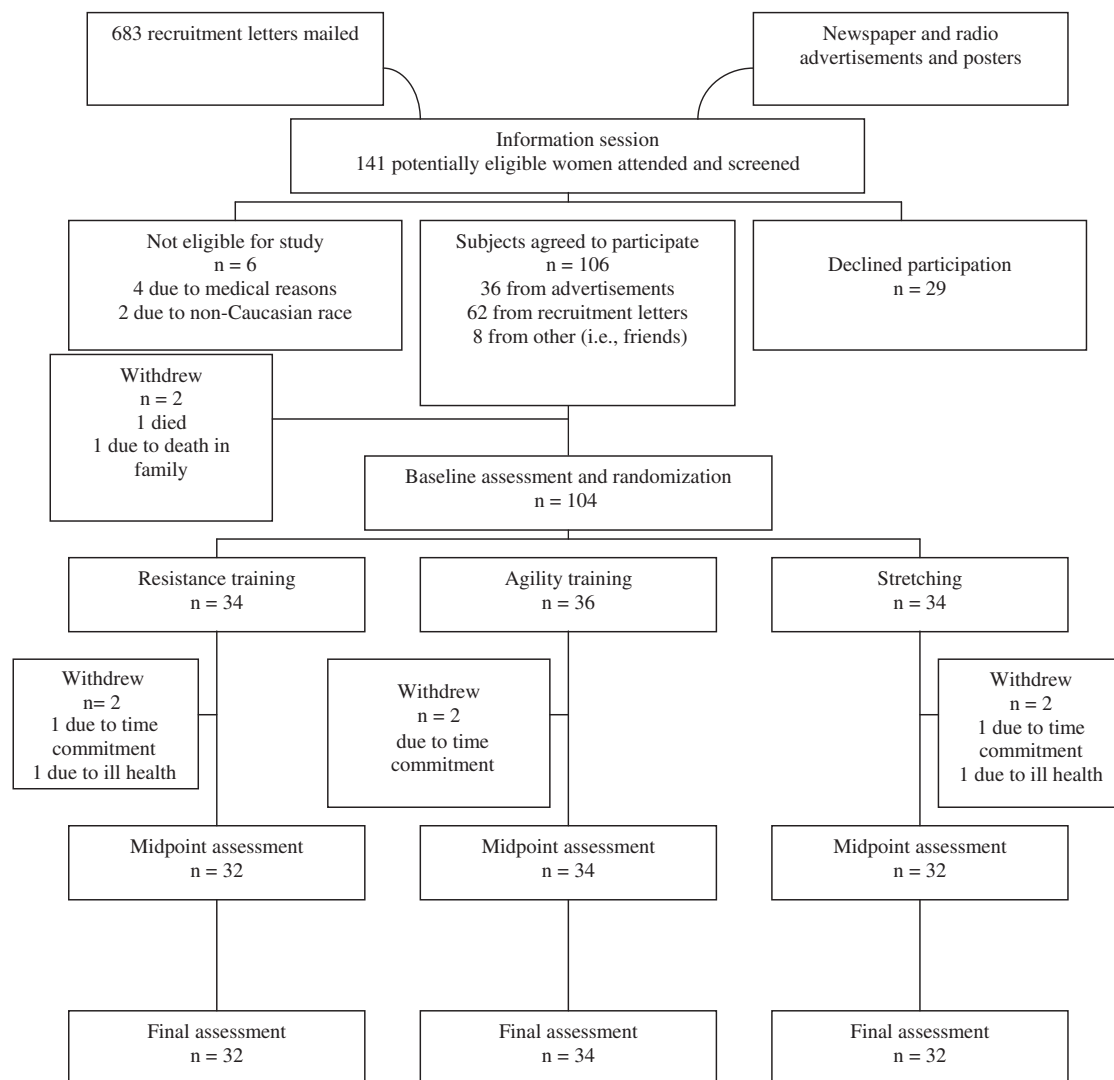


Figure 1. Flow chart outlining number of participants in each study arm.

PPA computes a fall risk score (standardized score) for each individual; this measure has a 75% predictive accuracy for falls in older people.^{19,20} Standardized weightings for each of the five components were derived from a discriminant function for predicting multiple falls from the Randwick Falls and Fractures Study.²⁰ These weightings (canonical correlation coefficients) were -0.33 for edge contrast sensitivity, 0.20 for lower limb proprioception, -0.16 for isometric quadriceps strength, 0.47 for hand reaction time, and 0.51 for postural sway on a compliant foam rubber surface. Fall-risk scores below 0 indicate a low risk of falling, scores between 0 and 1 indicate a mild risk of falling, scores between 1 and 2 indicate a moderate risk of falling, and scores above 2 indicate a high risk of falling. Table 1 describes the tests from the short-form PPA assessment (Table 1).

Secondary Outcome Measures

Secondary outcome measures were included to assess lower limb function in domains not assessed by the short-form PPA and overall general balance and mobility. Isometric ankle dorsiflexion was assessed in a seated position with the

foot secured to a footplate and the angle of the knee positioned at 120 degrees. In three trials, the subject attempted maximal dorsiflexion of the ankle; the greatest force was recorded.¹⁸ Foot reaction time was assessed using a light as a stimulus and a foot-press as the response.¹⁸ General balance and mobility was assessed using the Community Balance and Mobility scale (CB&M scale),²² a performance-based balance and mobility measure consisting of 12 items each rated on a 5-point scale (85 points maximum). It includes items such as timed single-leg stand, tandem walking, and stair mobility. This scale was chosen because present balance and mobility measures do not adequately assess the higher levels of functioning expected in community-dwelling older people.^{23,24} Test-retest reliability for the CB&M scale indicates a high agreement between tests with an intraclass correlation coefficient of 0.98. The internal consistency of the scale is also high (Cronbach alpha = 0.96).²²

Randomization

After baseline measurement, participants were randomly assigned to one of three groups: resistance training, agility

Table 1. Physiological Profile Assessment (PPA) Short-Form Assessment

PPA Task	Description	Measure
Postural sway	Individuals were asked to stand as still as possible for 30 seconds on 15-cm-thick medium-density foam rubber mat with eyes open, wearing the Lord swaymeter, ²⁰ a 40-cm long rod with a vertically mounted pen at its end. The rod is attached to the participants by a firm belt and extends posteriorly. The pen records sway on a sheet of millimeter graph paper fastened to the top of an adjustable height table	Total sway path (mm) determined from the path traced
Quadriceps strength	A simple strain gauge was used to assess dominant quadriceps (isometric) strength to the nearest 0.5 kg. Participants were seated with the hip and the knee joint at 90° of flexion	Best of three trials (kg)
Hand reaction time	Used a light as the stimulus and depression of a switch by the finger as the response	Average of 10 trials (msec)
Proprioception	Participants, seated with eyes closed, were asked to align the lower limbs on either side of a clear acrylic sheet (60 cm by 60 cm by 1 cm) standing on edge and inscribed with a protractor	Difference (deg) in matching the great toes
Edge contrast sensitivity	The Melbourne edge test was used to assess this aspect of visual function. This test presents 20 circular patterns containing edges with reducing contrast. Correct identification of the orientation of the edge on the patches provides a measure of contrast sensitivity in decibel units (dB), where $dB = -10 \log_{10} \text{contrast}$	Number of the last correctly identified circle (dB)

training, and stretching (sham exercise). Randomization was stratified by baseline performance in postural sway.

Sample Size

The required sample size for this study was estimated based on predictions of 20%, 10%, and 0% change in the PPA's fall-risk score for the agility-training group, the resistance-training group, and the stretching group, respectively. Assuming a 30% attrition rate and using an alpha level of 0.05 or less, 30 participants per group ensured a power of greater than 0.80 to detect a 10% difference between groups.

Exercise Intervention

The exercise intervention began 1 week after the baseline measures were administered. Participants were required to attend their assigned exercise class twice weekly. All classes were held at a Young Men's Christian Association community center and led by certified fitness instructors. The classes were 50 minutes in duration, with a 15-minute warm-up, 20 minutes of core content, and a 15-minute cool down. The instructor-to-participant ratio was 1:2 for the resistance training class, 1:3 for the agility training class, and 1:4 for the stretching class. The head instructor of each class recorded attendance daily.

Resistance Training

The protocol for the resistance-training group was progressive and high intensity in nature, with the aims of

increasing muscle strength in the extremities and trunk. A Keiser Pressurized Air system (Keiser Corporation, Fresno, CA) and free weights were used to provide the training stimulus. Participants underwent a 2-week familiarization period with the equipment and the exercises. The resistance training exercises included biceps curls, triceps extensions, seated row, latissimus dorsi pull downs, mini-squats, mini-lunges, hamstring curls, calf raises, and gluteus maximus extensions on a mat.

The intensity of the training stimulus was initially set at 50% to 60% of one-repetition maximum (1RM) as determined at Week 2, with a work range of two sets of 10 to 15 repetitions and progressed to 75% to 85% of 1RM at a work range of six to eight repetitions (two sets) by Week 4. The training stimulus was increased using the 7RM method,²⁵ when two sets of six to eight repetitions were completed with proper form and without pain or discomfort, but squats, lunges, and gluteus maximus extensions did not follow the above guideline. These three exercises were performed initially with body weight, and loading was increased only when proper form was maintained for two sets of 10 repetitions. The number of sets completed and the load lifted for each exercise were recorded for each participant at every class.

Agility Training

The aims of the agility training protocol were to challenge hand-eye coordination, foot-eye coordination, dynamic balance, standing and leaning balance, and psychomotor performance (reaction time). Ball games, relay races, dance

movements, and obstacle courses were used to achieve these goals. A logbook was maintained detailing the content of each week's classes and is available from the first author (TLA). Due to the potential risk of falls in the agility training class, participants were given KPH (Tampere, Finland) hip protectors, and all instructors provided close supervision and "spotting," as in gymnastics training.

Stretching (Sham Exercise)

The content of the stretching classes consisted of stretching exercises, deep breathing and relaxation techniques, and general posture education. There is no evidence that these exercises reduce fall risk.²⁶ This group served to control for confounding variables such as physical training received by traveling to the community center for twice-weekly classes, social interaction, and changes in lifestyle secondary to study participation.

Adverse Events

After each exercise session, participants were questioned about the presence of any adverse effects, such as musculoskeletal pain or discomfort. Modifications in training program were made on an individual basis as necessary. Any falls that occurred during the classes were recorded. Instructors also monitored participants for symptoms of angina pectoris and shortness of breath.

Statistical Analysis

The data were analyzed on an intention-to-treat basis, using SPSS statistical software (SPSS Inc., Chicago, IL). Data on all 98 participants were included in the analysis regardless of compliance. Variables that were not normally distributed (sway, hand and foot reaction time) were transformed using natural logarithm before comparisons between the groups were made. Comparisons of group characteristics and baseline scores were undertaken using a chi-square test for differences in proportions and analysis of variance (ANOVA) for differences in means. The fall-risk scores, fall-risk

score components, secondary outcome variables, and PASE scores measured at the 13- and 25-week retests were compared using forced-entry multiple linear regression analysis, with baseline scores and experimental group included as independent variables in the models. This analysis procedure provides a more precise indication of the treatment effect than provided by group-by-time analysis of variance. Post hoc analyses were then performed in which there were significant main effects, using Scheffe corrections. Multivariate analysis of variance (MANOVA) with repeated measures was used to examine whether there were changes in fall risk at the end of the trial compared with baseline and 3 months in the agility- and resistance-training groups. In these analyses, polynomial contrasts were selected giving measures of linear and quadratic (nonlinear or asymptotic) trends.

Finally, Pearson correlations were computed to determine whether changes in the squat load normalized for body weight (load change/weight) between the beginning and the end of the intervention period were related to reductions in postural sway in the resistance-training group.

RESULTS

Descriptive Variables, Exercise Adherence, and Physical Activity Levels

The mean age \pm SD of the cohort was 79 ± 3 . The three groups did not differ in any of the descriptive variables (Table 2). In the group as a whole, adherence to the exercise classes was 83.3%. The resistance-training group had an average compliance of 85.4%; the agility-training group, 87.3%; and the stretching group, 78.8%.

Physical activity levels (PASE scores) increased during the 25-week intervention period in all three groups ($P = .008$), but these changes did not differ significantly between the groups ($P = .60$), and changes in PASE scores were not significantly related to changes in the primary or any secondary outcome measures ($r \leq 0.114$, $P \geq .266$).

Table 2. Descriptive variables at baseline (N=90)

Variable	Resistance (n = 32)	Agility (n = 34)	Stretching (n = 32)
Age, mean \pm SD	79.6 \pm 2.1	78.9 \pm 2.8	79.5 \pm 3.2
Height, cm, mean \pm SD	160.1 \pm 6.0	157.0 \pm 6.1	158.3 \pm 8.4
Weight, kg, mean \pm SD	59.9 \pm 9.4	62.5 \pm 9.3	65.2 \pm 12.6
Prescribed medications, n, mean \pm SD	2.6 \pm 2.3	3.2 \pm 2.1	4.1 \pm 3.3
High-contrast acuity, mean \pm SD*	1.5 \pm 0.9	2.4 \pm 4.4	1.5 \pm 0.6
Low-contrast acuity, mean \pm SD*	2.6 \pm 1.6	3.8 \pm 4.7	2.9 \pm 1.3
Tactile sensitivity, mean \pm SD [†]	4.4 \pm 0.5	4.3 \pm 0.5	4.1 \pm 0.6
MMSE score, mean \pm SD (max 30 points)	28.7 \pm 1.4	28.6 \pm 1.4	28.3 \pm 1.9
Number of classes attended, mean \pm SD	41.0 \pm 9.4	41.9 \pm 6.1	37.8 \pm 10.1
Baseline Physical Activity Scale for the Elderly, mean \pm SD	98.0 \pm 51.8	83.3 \pm 35.1	76.3 \pm 30.0
Fall in last 4 weeks, n (%)	5 (15.6)	1 (2.9)	2 (6.3)
Osteoarthritis, n (%)	11 (34.4)	13 (38.2)	17 (53.1)
Osteoarthritis of the knee, n (%)	5 (15.6)	6 (17.6)	6 (18.8)
Use of walking aid, n (%)	4 (12.5)	2 (5.9)	5 (15.6)

Note: There were no significant differences between the groups for any measure.

* Measured in terms of the minimum angle resolvable in minutes of arc.

[†] Measured in logarithms of milligrams pressure.

n = number of "yes" cases within each group; % = percentage of "yes" cases within each group.

PPA Fall Risk Score, Fall Risk Components, and Secondary Outcome Measures

Table 3 shows the baseline, 13-week, and 25-week retest results for the fall-risk scores, fall-risk score components, and secondary outcome measures for the three study groups (Table 3). The regression analyses revealed a significant difference in one measure only (CB&M scale scores) at the midpoint of the trial. Post hoc test showed that the agility-training group showed significantly more improvement in this measure than the other two groups.

At the end of the trial, there were group differences for the fall risk score and postural sway on the compliant foam rubber mat. The groups did not differ in the remaining fall-risk component or secondary outcome measures, although for both reaction-time tasks, between-group differences approached statistical significance—hand reaction time ($F_{2,94} = 2.49, P = .09$) and foot reaction time ($F_{2,94} = 2.65, P = .08$).

Post hoc analyses indicated that the resistance-training and agility-training groups had significantly lower fall-risk

scores than the stretching group at the end of the intervention period. PPA fall-risk scores were reduced 57.3% and 47.5% in the resistance- and agility-training groups, respectively, but only 20.2% in the stretching group. In the resistance and agility groups, the reduction in fall risk was mediated primarily by improved postural stability, with sway reduced 30.6% and 29.2%, respectively. In contrast, sway showed no significant change in the stretching group (0.0%).

The agility- and resistance-training groups showed continued improvements in fall risk throughout the intervention period (Figure 2). The repeated measure MANOVA analysis indicated a significant linear contrast ($P < .001$) and an insignificant quadratic contrast ($P = .15$) for change in fall risk in the resistance-training group. In the agility-training group, there were significant linear ($P < .001$) and quadratic contrasts ($P < .05$), indicating that improvement beyond the midpoint of the trial was less marked.

Table 3. Outcome Measures: Baseline, Midpoint, and Final (N = 98)

Variable	Baseline	Midpoint	Final
	Mean \pm Standard Deviation		
Resistance (n = 32)			
Fall-risk score	2.2 \pm 0.7	1.4 \pm 1.0	1.0 \pm 1.0 [†]
Postural sway, mm	230.1 \pm 93.1	183.6 \pm 123.2	159.6 \pm 82.0 [‡]
Quadriceps strength, kg	17.2 \pm 7.2	20.4 \pm 8.4	18.9 \pm 8.6
Hand reaction time, msec	328.3 \pm 44.3	284.1 \pm 49.3	267.8 \pm 52.3
Proprioception, deg	2.2 \pm 2.1	1.9 \pm 1.0	1.5 \pm 1.2
Edge contrast, dB	17.8 \pm 2.1	19.3 \pm 2.0	19.2 \pm 2.2
Dorsiflexion strength, kg	6.4 \pm 2.2	7.3 \pm 2.6	7.6 \pm 2.5
Foot reaction time, msec	380.5 \pm 81.6	320.1 \pm 41.6	331.2 \pm 63.9
CB&M scale (out of 85 points)	44.6 \pm 21.6	49.5 \pm 20.7	51.2 \pm 21.9
Agility (n = 34)			
Fall-risk score	2.4 \pm 0.9	1.5 \pm 1.0	1.7 \pm 0.9 [†]
Postural sway	219.2 \pm 80.3	179.5 \pm 98.1	155.3 \pm 91.2 [‡]
Quadriceps strength	17.0 \pm 6.5	19.9 \pm 6.2	17.2 \pm 7.9
Hand reaction time	337.8 \pm 61.4	298.6 \pm 53.6	294.9 \pm 55.1
Proprioception	1.8 \pm 1.2	1.8 \pm 1.6	1.5 \pm 1.2
Edge contrast	17.3 \pm 2.3	18.9 \pm 2.1	18.7 \pm 2.7
Dorsiflexion strength	5.1 \pm 2.6	7.3 \pm 1.9	6.8 \pm 2.9
Foot reaction time	379.0 \pm 67.8	340.2 \pm 68.1	353.9 \pm 61.6
CB&M scale	39.9 \pm 17.5	51.5 \pm 15.5*	48.9 \pm 16.4
Stretching (n = 32)			
Fall-risk score	1.9 \pm 0.8	1.5 \pm 1.0	1.5 \pm 1.2
Postural sway	217.0 \pm 104.7	196.6 \pm 122.9	217.4 \pm 148.3
Quadriceps strength	16.1 \pm 7.2	19.2 \pm 7.2	17.5 \pm 6.4
Hand reaction time	307.6 \pm 43.1	290.5 \pm 49.1	280.7 \pm 60.2
Proprioception	1.7 \pm 0.9	2.0 \pm 1.6	1.8 \pm 1.2
Edge contrast	18.0 \pm 1.5	18.8 \pm 1.8	18.6 \pm 1.9
Dorsiflexion strength	5.4 \pm 2.9	6.4 \pm 2.8	6.3 \pm 2.4
Foot reaction time	362.8 \pm 57.6	332.3 \pm 49.8	345.2 \pm 57.5
CB&M scale	40.4 \pm 18.3	45.8 \pm 17.8	45.0 \pm 17.4

Note: High fall-risk scores, high sway values, high reaction time values, low quadriceps strength values, and low edge contrast scores indicate impaired performances. For the Community Balance and Mobility (CB&M) Scale, a higher score indicates better physical function.

* Significantly different from the resistance training and stretching groups at $P < .05$.

[†] Significantly different from the stretching group at $P < .01$.

[‡] Significantly different from stretching group at $P \leq .05$.

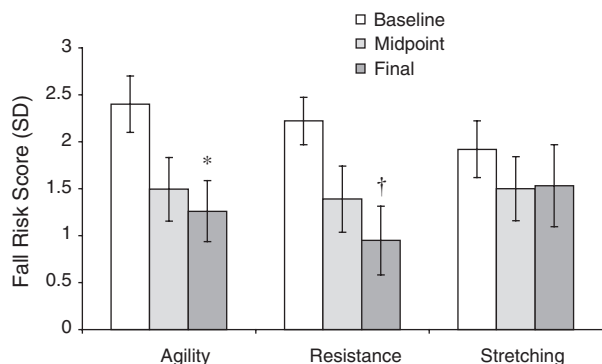


Figure 2. Fall-risk score. *Significantly different from the stretching group, $P = .005$. †Significantly different from the stretching group, $P = .001$. Error bars represent 95% confidence intervals. SD = standard deviation.

Changes in Squat Load and Sway in the Resistance-Training Group

Over the trial period, squat load normalized to body weight (load (kg)/weight (kg)) used in the exercise regime for the resistance-training group increased by $16.5 \pm 5.2\%$. Increases in squat load were significantly associated with reductions in postural sway scores ($r = -0.45$, $P < .01$).

Adverse Events

Musculoskeletal complaints (e.g., sore neck, bursitis of the hip) developed in 10 women in the resistance-training group, three in the agility-training group, and two in the stretching group. All musculoskeletal complaints resolved or diminished within 3 weeks of onset, and none required a physician's attention. Four participants in the agility-training group experienced shortness of breath that required them to stop participating for 5 minutes before continuing. There were two missteps (one participant) and six falls (four participants) in the agility-training group. None of the falls in class resulted in injuries requiring medical attention.

Falls

Based on the fall diaries, which excluded falls that occurred in classes, there were 18 falls in the resistance-training group (one subject fell seven times), 11 falls in the agility-training group, and 10 falls in the stretching group during the 25-week intervention period. There were 10 frequent fallers, defined as women having more than one fall during the intervention period: three in resistance-training group, five in the agility-training group, and two in the stretching group.

DISCUSSION

High-intensity resistance training and agility training were more effective in reducing fall risk than a stretching program in older community-dwelling women with low bone mass. After 25 weeks of intervention, resistance training and agility training significantly reduced the fall risk score, by 57% and 48%, respectively, compared with

only a 20% reduction in the stretching group. Based on normative data study,²⁰ these changes represent a reduction in the risk of falling over 12 months from more than 80% to 50% to 55%.

Of the five components that contribute to the calculation of the fall-risk score, it was hypothesized that postural sway, quadriceps strength, and hand reaction time would be amenable to change by the intervention programs. Resistance training and agility training resulted in significantly better postural stability than in the stretching group, but these two groups did not differ significantly in the tests of strength and reaction time at the end of the trial. This indicates that, for both groups, the reduction in fall risk scores was primarily mediated by improved postural stability.

The finding that agility training improved postural stability is consistent with previous investigations in other populations of older people,^{4,27,28} but the finding that resistance training improved postural stability contrasts with some previous studies.^{29,30} The inconsistencies in the findings here may relate to differences in the intensity of the resistance-training programs used across studies. For example, the current study and another study³¹ used high-intensity resistance-training programs—75% to 85% of 1RM and two sets of six to eight repetitions versus 85% of 1RM and three sets of eight repetitions. In contrast, studies with lower-intensity interventions, such as 70% to 75% of 1RM and 13RM²⁹ or home-based lower-extremity resistance-training program using Thera-Bands or body weight,³⁰ have not been found to be effective in improving balance.

Although not reflected by the seated isometric knee extension test, the resistance-training group significantly increased the squat load used in the exercise program. The lack of significant improvement in the strength outcome measure may reflect the specificity of training (standing squats) that differed from the conditions for testing (seated-knee extension). Others, who found that athletes who trained with standing squats demonstrated significant strength gains in a 1RM standing-squat test but not in a seated-knee extension test, have reported the lack of generalization across strength measures.³² Increases in squat load were significantly associated with reductions in sway scores on the compliant foam rubber mat; this interesting association may indicate how resistance training is related to improved balance and reduced falls risk.

It has been postulated that regular exercise may maintain the reactive capacity of older people by delaying the deterioration of the dopamine systems, enhancing cerebral circulation integrity, and providing trophic influence on the neurons that supply the muscle fibers.³³ There were strong trends that indicated that the agility- and resistance-training groups had faster reaction times at the end of the trial for finger and foot-press response, but these differences did not reach statistical significance. Significant improvements may have been evident with a longer intervention period or with increased power with a slightly larger sample.⁴

At the study midpoint (13 weeks), there were few differences between the groups, but further improvements occurred in the second period of the trial in the resistance and agility groups, so that significant differences were

apparent for the fall risk and postural sway measures. This would indicate that trials of 6-months duration or more are necessary to obtain maximal beneficial intervention effects. Improvement in general CB&M scores was apparent in the agility-training group at 13 weeks, but the relative improvement over the other groups was not maintained at the study endpoint. This may be due to the lack of established protocols and appropriate safe environment for progressing in an agility-training program, compared with a resistance-training program. Furthermore, all three groups showed improvements in this measure at the end of the trial, which may reflect direct participation in the programs, indirect activity associated with attending the classes, and increased activity outside the program as indicated by the changes in PASE scores.

The resistance and agility programs were feasible for older adults with low bone mass, but the agility-training program carried a higher risk of falls than the resistance training. The agility-training program required considerable planning and many safety precautions. Furthermore, the progression of an agility-training program, unlike a resistance-training program, is not well defined in the clinical or research setting. Although adverse effects also occurred in the resistance-training group, short-term musculoskeletal complaints are less disabling than sustaining a hip fracture from a fall. Thus, a community-based agility program is more difficult to deliver outside of the research setting than is a resistance-training program. However, it was clear that the agility-training participants found the program particularly enjoyable, which may enhance long-term compliance.

The study has certain limitations. First, the interventions were staff intensive, and their availability in the health system may be limited by cost. Second, the primary study outcome was fall risk, as opposed to falls. Thus, future research using falls as the primary outcome measure is needed to confirm the role of resistance training and agility training in falls prevention in those with low bone mass. It would also be useful to contrast the interventions against proven fall-prevention interventions.

In conclusion, high-intensity resistance training and agility training resulted in significantly lower fall risk in older women with low bone mass than did a stretching program. Furthermore, this study demonstrated that this group has the capacity to participate in demanding exercise programs with acceptable risk. These exercise programs may have particular public health benefits, because it has been shown that older women with low bone mass are at increased risk of falling and sustaining fall-related fractures.

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