The Effect of a 12-Month Exercise Trial on Balance, Strength, and Falls in Older Women: A Randomized Controlled Trial

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OBJECTIVE: To determine whether a 12-month program of regular exercise can improve balance, reaction time, neuromuscular control, and muscle strength and reduce the rate of falling in older women.

DESIGN: A randomized, controlled trial of 12 months duration.

SETTING: Conducted as part of the Randwick Falls and Fractures Study in Sydney, Australia.

PARTICIPANTS: One hundred ninety-seven women aged 60 to 85 years (mean age 71.6, SD = 5.4) who were randomly recruited from the community.

OUTCOME MEASURES: Accidental falls, postural sway, reaction time, neuromuscular control, and lower limb muscle strength.

MAIN RESULTS: Exercise and control subjects were tested before, midway through, and at the end of the trial. At initial testing, exercisers and controls performed similarly in all tests and were well matched in relevant health and lifestyle factors. The mean number of classes attended for the 75 exercise subjects who completed the program was 60.0 (range 26–82). At the end of the trial, the exercise subjects showed improved performance in all five strength measures, in reaction time, neuromuscular control, body sway on a firm surface with the eyes open, and body sway on a compliant surface with the eyes open and closed. In contrast, there were no significant improvements in any of the test measures in the controls. In one test measure, hip flexion strength, the exercisers showed continued improvement throughout the study year. There was no significant difference in the proportion of fallers between the exercise and control subjects. Interesting trends were evident, however, between falls frequency and adherence to the exercise program.

CONCLUSIONS: These findings show that exercise can produce long-term benefits with regard to improving sensorimotor function in older persons. The findings also suggest that high compliance to an exercise program may reduce fall frequency, although further studies are required to conclusively demonstrate that exercise offers an effective means of preventing falls. J Am Geriatr Soc 43:1198–1206, 1995.

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Exercise is considered to be a universally accessible and inexpensive form of prevention that is noninvasive and under proper supervision carries few risks.[1] However, while the role of exercise in the maintenance of good health and mobility in older adults is generally accepted, the specific benefits of different types of exercise on various physiological systems is still largely in question, particularly with regard to the physiological systems that contribute to stability.[2]

Several studies have found that adherence to a regular exercise program can significantly improve muscle strength,[3–8] and in two studies a significant improvement in reaction time following regular exercise programs has been found.[9,10] The studies that have measured the effects of exercise trials on balance control, however, have produced conflicting results. Era[11] and Johansson and Jarnlo[12] have reported significant improvements in measures of postural sway following exercise trials, while Crilly et al.,[1] Lichtenstein et al.,[13] and McMurdo and Rennie[14] have reported weak to negligible effects of exercise training on body sway. A study by Parsons et al.[15] that assessed the effect of exercise training on balance, using stable and moving platforms, found a significant improvement on the moving platform only.

All of these trials that have examined the effects of exercise on sensorimotor and balance parameters have been of a pilot nature and have had small sample sizes, usually between 10 and 50 subjects. Other limitations have included inadequate compliance with the exercise programs, high drop-out rates of up to 50%, baseline differences between intervention and control groups, and ineffective or inadequate duration of exercise programs.

Although the existing evidence is sufficient to suggest that older people should exercise, further studies are required, particularly with regard to exercise type, intensity, frequency, and duration, to elucidate the role exercise can play in improving sensorimotor function in older people. Such research has important practical implications inasmuch as it has been found in cross-sectional studies that impaired strength, reaction time and stability are associated with falls

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in older persons,[16–18] although it is yet to be shown whether exercise interventions can prevent falls.[19]

In this study we have attempted to address these issues by undertaking a long-term, randomized, controlled trial of exercise in a sample of nearly 200 older women recruited from the community. Our aim was to assess whether exercise has beneficial effects on muscle strength, neuromuscular control, reaction time, and body sway and whether such an exercise program can play a role in reducing falls frequency.

METHODS

Subjects

The sample comprised women aged 60 years and older who took part in the Randwick Falls and Fractures Study between 1988 and 1991.[20] The women, who were living independently in the community, were initially recruited from 64 randomly selected Census collector's districts in the Randwick local government area in Sydney, Australia. All women aged 65 years and older living within these districts (who were identified using extracted information from the electoral roll) were invited to take part in the study. The only exclusion criteria were not living at the dwelling at the time of the study or having no or very little English. Seven hundred four women (60% of those eligible) participated in the initial phase of the study, that is, they completed a structured interview containing questions about falls frequency and related health and lifestyle factors. No significant differences were found between the initial study sample and the reference population with regard to age-structure, marital status, and employment status (whether or not still in the work force). A full description of the sample characteristics and recruitment procedures for the Randwick Falls and Fractures study have been reported elsewhere.[20]

In early 1992, the coded identification numbers of 374 subjects from the Randwick Falls and Fractures Study were randomly assigned to either the exercise or control recruitment pools so as to have equal numbers in each pool. At this stage, it was found that nine women had died since taking part in the initial survey, and 21 were not living at the same address. A further 35 women could not be contacted despite six attempts (three letters and three home visits). Women were excluded from taking part if they were ill and/or immobile, were in the hospital, had a medical condition involving the neuromuscular, skeletal, or cardiovascular system that precluded taking part in an exercise program (as determined by a physician at pretest), had little English, or were already attending exercise classes of equivalent intensity to the study intervention. The number of women in each exclusion category and the number of women who declined to take part for both the exercise and control groups are shown in Table 1.

One hundred ninety-seven women (74.1% of those eligible) took part in the exercise trial. The mean age of the 100 women in the exercise group was 71.6 years (SD = 5.5), which was almost identical with the mean age of the 97 controls - 71.7 years (SD = 5.3), (t_{195} = .06, P = .95). The exercise and control groups were also well matched for height (exercisers: mean = 1.58 m, SD = 0.60; controls: mean = 1.57 m SD = 0.66), and weight (exercisers: mean = 66.5 kg, SD = 12.0; controls: mean = 64.9 kg SD = 14.5) and were similar across a number of health and lifestyle measures. Table 2 shows the numbers and proportions in each group who reported medical conditions, falls, instability, drug use, and inactivity. The presence of one or more of these conditions did not preclude any of the exercise subjects from taking part in the program.

Table 1. Number of Women Who Were Excluded from the Study or Who Declined to Participate

	Exercisers	Controls
Exclusions		
Ill and/or immobile	18	12
In hospital	2	2
At medical assessment	2	0
Attending exercise classes	4	1
Poor English	2	0
Total excluded	28	15
Declined		
Too busy	17	6
Not interested	24	22
Total declined	41	28

Table 2. Medical Conditions, Stability, Drug Use and Inactivity at Pretest

	Exercisers		Controls	
	n	(%)	n	(%)
Medical conditions				
Osteoarthritis	35	(35.0)	25	(25.8)
High blood pressure	37	(37.0)	26	(26.8)
Heart disease	10	(10.0)	13	(13.4)
Stability				
1+ falls*	28	(28.0)	28	(28.9)
Falls risk†	37	(37.0)	35	(36.1)
Unsteadiness‡	8	(8.0)	5	(5.2)
Drug use				
4+ drugs	22	(22.0)	19	(19.6)
Cardiovascular system drugs	45	(45.0)	39	(40.2)
Central nervous system drugs	35	(35.0)	29	(29.9)
Psychoactives	26	(26.0)	20	(20.6)
Nonsteroid anti-inflammatory agents	24	(24.0)	17	(17.5)
Inactivity				
Walk <15 min§	15	(15.0)	7	(7.2)
<1 planned walk/week	60	(60.0)	47	(48.5)
<1 hr activity/day‖	23	(23.0)	22	(22.7)

* Number of falls in the initial prospective study (12-month follow-up).
† Subjective fall risk: mod/high vs low.
‡ Unsteadiness: those who rated their balance as unsteady rather than steady.
§ Can walk for only 15 minutes or less before needing a rest.
‖ Participation in organized sports and activities, planned walks, and general activity (i.e., walking, gardening).
Chi-square tests for cross-tabulation tables revealed no significant differences between exercisers and controls.

The Exercise Program

The exercise classes, part of an existing community-based program, were held in two sites within the Randwick local government area (a community hall and a public hospital) that were easily accessible by public transport. This program followed the New South Wales State Schools timetable. Classes ceased during school holidays, allowing participants to plan their own holidays and take part in other activities such as caring for grandchildren.

The exercisers participated in approximately 1-hour exercise sessions twice weekly for four 10 to 12-week terms (with 2-week interterm breaks and a 5- week Christmas/Summer holiday break). The classes were divided into four sections: a 5-minute warm up period, a 35-minute conditioning period, a 15- minute stretching period, and a 5 to 10-minute relaxation (cool down) period.[21] The exercises were undertaken as group activities, with a major emphasis on social interaction and enjoyment. Most of the activities were done with the accompaniment of music.

Warm-Up Period

The warm-up period commenced with moderate paced walking. After 2 to 3 minutes, arm movements were included to increase heart rate.

Conditioning Period

The conditioning period contained aerobic exercises, strengthening exercises, and activities for balance, flexibility, endurance, and hand-eye and foot-eye coordination.

The aerobic exercises involved continuous movement of the legs and trunk and intermittent movement of the arms. The leg movements were designed to use the full range of movement of the hip, knee and ankle joints, and to condition and strengthen all major muscle groups. These included movements that extend, flex, abduct, adduct and rotate the leg and foot such as side-stepping; fast walking; forward and backward stepping; leg lifts; placing foot to the front, side and behind; knee bends; forward and side lunging and heel rises.

The trunk movements were designed to maintain flexibility of the spine, and to condition and strengthen the back, chest, abdominal, and pelvic floor muscle groups. These included movements that rotate, flex, and extend the neck, back, and pelvis such as twisting the upper body, body bends, neck side flexion and rotation, knee lifts, opposite elbow to raised knee, pelvic rocking, pelvic floor contractions, and belly dancing techniques.

The arm movements were designed to use the full range of movement of the shoulder, elbow, and wrist joints and to strengthen all major muscle groups. These included movements, such as circling the arms, biceps curls, bench press, upright row, short and long arm shoulder lever, mock boxing, shoulder rolls, and shrugs, that extend, flex, abduct, adduct, and rotate the arm and hand

The activities for balance and hand-eye and foot-eye coordination included standing on one leg with the other leg raised, ballgames requiring catching with one hand while standing or moving, kicking a moving ball, throwing to a moving target, running under a skipping rope, and team ballgames.

Strengthening exercises included lifting one's own body weight (e.g., modified push-ups) and opposing muscle groups resistance exercises (e.g., while seated and lifting a leg off the floor while resisting movement with the hand pressing down on the knee).

Stretching

Participants undertook the stretching exercises while sitting on a chair or on the floor. All muscle groups were stretched. The muscles were slowly elongated and held for at least 20 seconds. Participants were encouraged to breath and relax throughout each stretch.

Relaxation

In this period, participants sat on a chair or on the floor or lay on the floor. A variety of techniques were used, including muscle relaxation, concentration on specific body areas, controlled breathing, and guided imagery.[22]

Sensorimotor Function Assessments

The assessment, which took approximately 20 minutes, included tests of muscle strength, reaction time, neuromuscular control, and body sway. These test measures were chosen to gain quantitative measurements of the physiological systems outlined in our conceptual model[23] as major contributors to balance control, in which exercise could theoretically have a beneficial effect on function. The tests were administered by two investigators (SL and PW), who were not blind to treatment status. Identical test procedure instructions were, therefore, given to all subjects in both treatment groups. The subjects were tested at a balance and gait laboratory at the University of New South Wales before the trial, at 22 weeks, and at the end of the 12-month trial.

Muscle Strength

The strength of five muscle groups in the dominant leg was measured. Testing of the hip and knee muscle groups was performed using a strap assembly, incorporating a strain gauge load cell, which was connected to an amplifier with the outgoing signal recorded on a chart recorder.

The hip flexors and extensors were measured while the subject was standing by placing a strap around the subject's leg just proximal to the knee joint. The subject's torso was supported by a padded rest during the tests to minimize recruitment of other muscle groups. The knee flexors and extensors were measured while the subject was sitting on a tall chair by placing a strap around the leg just proximal to the ankle joint. In three experimental trials per muscle group, the subject pulled against the strap assembly with maximal force, with the greatest force for each muscle group recorded.

The testing of the ankle dorsiflexion was performed using a specially designed ankle strength testing device which used a pivoted platform attached to a strain gauge load cell and connected to the same instruments as above. While the subject was sitting on a tall chair, the foot was secured to the pivoted platform. In three experimental trials, the subject attempted to maximally dorsiflex in the device and the greatest force was recorded.

Reaction Time

Reaction time was assessed using a simple reaction time paradigm, employing a light as the stimulus and depression of a switch by the foot as the response. The seated subject placed the dominant foot on a footrest hinged to a base plate. A switch recorded how quickly the footrest was pressed. A variable delay between depression of the experimenter's switch and the activation of the timer and the light stimulus (1–5 seconds) eliminated the auditory cue of the experimenter's switch. Subjects had 10 practice trials and 10 experimental trials.

Neuromuscular Control

Neuromuscular control was measured using the same apparatus as was used for measuring reaction time. In this task, the subject (again seated) pressed and depressed the footrest with the dominant foot as many times as possible in a period of 8 seconds. The switch below the baseplate recorded how many times the footrest was pressed. The subject had a number of practice trials with the device and then undertook two experimental trials, with the higher number of footrest presses taken as the measure of neuromuscular control.

Body Sway

Body sway was measured using a sway meter. The device consisted of a rod attached to the subject at the waist level by a firm belt. A pen mounted vertically at the end of the rod recorded the movements of the subject on a sheet of graph paper (with a millimeter square grid), which was fastened to the top of an adjustable height table. The subject was instructed to stand with feet comfortably apart on a firm base as motionless as possible for a period of 30 seconds while fixating a point at eye level at a distance of 3 meters. The test procedure was then repeated under a further three conditions; standing on a firm base with the eyes closed, standing on high density foam rubber (70 cm by 62 cm by 15 cm thick) with the eyes open, and standing on the foam rubber with the eyes closed. The foam was used to reduce proprioceptive input from the ankles so that subjects were required to rely on visual and/or vestibular cues to maintain a steady stance. Total sway (number of square millimeter squares traversed) in the 30-second test periods were recorded for the four test conditions.

Full descriptions of the apparatus and procedures, along with test-retest reliability scores for the test measures, have been reported elsewhere.[24]

Falls Definitions and Follow-up Procedure

For the purposes of this study, a fall was defined as an event that resulted in a person coming to rest unintentionally on the ground or other lower level, not as the result of a major intrinsic event or an overwhelming hazard.[16] Details on fall types, injuries, and locations was also obtained. An attempt was made to distinguish those who suffered the occasional accidental fall from those who suffered pattern or intrinsic falls.[17,18] As such, an accidental faller was defined as a subject who (1) fell one time only in the follow-up year, (2) fell as a result of a trip or a slip, but not because of poor balance, legs giving way, or if they were not sure what caused the fall, and (3) stated that they would have fallen in the same circumstances if they were 30 years younger.[25] Questionnaires were mailed to exercise and control subjects every 2 months, along with a reply paid envelope. If subjects failed to return the questionnaire, further contact was made by telephone interview.

Statistical Analysis

Sensorimotor Performance

Chi-square tests for cross-tabulation tables and Students *t* tests were used to compare the prevalence of health and lifestyle factors and the means of the test measures of the exercise and control groups at initial assessment. A repeated measures multiple analysis of variance was used to compare changes in test performance at the end of the program (a within subjects factor) between the exercise and control groups (a between subjects factor). Univariate analyses were then performed to assess which of the individual strength, speed, and sway variables demonstrated significant differences. As the sway measures had right skewed distributions, logarithms of these variables were calculated and examined in the analyses. Multiple analysis of variance with repeated measures was also used to examine whether there were changes in the sensorimotor and balance test measures at the end of the study year (compared with baseline and 22 weeks) in the exercise subjects. In these analyses, polynomial contrasts were selected, giving measures of linear and quadratic (i.e., nonlinear or asymptotic) trends. Finally, chi-square tests for cross-tabulation tables were used to compare the proportions of subjects in each group who recorded distinct improvements in the tests (defined as a 10% increase in the strength tests, a 5% reduction of reaction time, a 5% increase in neuromuscular control, and a 10% reduction in the sway tests).

Falls

Comparisons of falls frequency between the groups was undertaken using three methods: (1) calculating the total number of falls in each group, (2) calculating the number of fallers in each group (i.e., those who fell one or more times in the follow-up year) and (3) calculating the number of multiple fallers in each group (i.e., those who fell two or more times in the follow-up year). The proportion who suffered "nonaccidental" falls and "balance-related" falls were also determined. Finally, falling rates among low and high adherers to the exercise program were compared. The data were analysed using the SPSS computer package.[26]

RESULTS

Attendance and Adherence

Of the 100 subjects who were recruited into the study as exercise subjects, 75 attended 26 or more classes throughout the study year and were available for the 12-month retest. Of

Table 3. Mean Values (SDs) for the Test Measures at Pretest

	Exercisers (n = 100)		Controls (n = 97)	
Strength (kg force)				
Ankle dorsiflexion	7.6	(2.5)	7.5	(2.3)
Knee extension	20.9	(6.9)	22.3	(8.5)
Knee flexion	12.1	(3.9)	12.1	(4.3)
Hip extension	21.4	(8.0)	20.4	(8.4)
Hip flexion	22.8	(6.8)	23.3	(7.6)
Reaction time (msecs)	286	(64.0)	281	(44.0)
Neuromusc control (taps/8 secs)	30.2	(6.1)	31.4	(6.8)
Sway (mm squares traversed in 30 secs)				
Eyes open (floor)	59	(22.0)	60	(30.0)
Eyes closed (floor)	76	(47.0)	77	(59.0)
Eyes open (foam)	106	(47.0)	117	(65.0)
Eyes closed (foam)	163	(66.0)	167	(78.0)

Students *t* tests revealed no significant differences between exercisers and controls.

the 25 subjects who failed to complete the program, three died, one suffered a stroke, two suffered an injurious fall, four had medical conditions that precluded continued participation: arthritis (2), vertigo, leg laceration, and two moved from the study area. The remaining 13 subjects dropped out at or before the mid-point of the study, attending between one and 14 classes.

The mean number of classes attended for the 75 exercisers who adhered to the program was 60.0 (73.2%). The range was 26–82 classes (32%-100%) with 59 subjects (79%) attending 50 or more classes. Five subjects who dropped out of the program, who attended between one and 14 sessions, were also retested for sensorimotor function at the end of the trial. The number of sessions attended (when including the results of the dropout subjects) was significantly associated with degree of improvement in the tests of reaction time and knee flexion strength ($r = .25$, $P < .05$ and $r = .24$, $P < .05$ respectively).

Effects of Exercise on Sensorimotor Function

The mean values plus standard deviations for the test measures at initial assessment for the 100 exercisers and 97 controls recruited into the program are shown in Table 3. The baseline scores were very similar with no statistically significant differences between the groups. Further, no significant differences in the baseline test measures were evident when data from the 75 exercisers who completed the trial and the 76 controls available for retest were compared. These retested sub-groups also did not differ on any of the health and lifestyle measures.

Mean scores for the test measures at baseline, 22-weeks, and 12 months for the exercisers who completed the program and the controls available for retest at the end of the 12-month trial are shown in Table 4. The multiple analysis of variance revealed a significant group by time effect ($F_{11,135} = 8.15$, $P < .001$), indicating an improvement in the test measures in the intervention group but little or no change in the control group. Compared with baseline scores, the univariate analyses showed performance of exercise subjects improved significantly in all tests with the exception of sway with eyes open on the floor at the 22-week retest and all tests with the exception of sway with eyes closed on the floor at the 12-month retest. The control subjects recorded a small improvement in one test: ankle dorsiflexion strength, but in all other tests, 12-month retest scores were similar to or worse than test scores at baseline. A similar pattern was also evident when retest performances were measured for whether subjects achieved distinct gains (Table 5).

The exercise group maintained improvement throughout the program in most tests as indicated by similar test scores at 22 weeks and 12 months. Exercisers, however, showed continued improvement in hip extension as indicated by a signif-

Table 4. Mean Values (SDs) for the Test Measures—Baseline, 22 Weeks and 12 Months

	Pretest	22 Weeks	12 Months
Exercisers (n = 75)			
Strength (kg force)			
Ankle dorsiflexion	7.8 (2.4)	9.0 (2.1)**	9.0 (1.9)*
Knee extension	22.2 (6.8)	26.8 (8.1)**	28.1 (9.5)**
Knee flexion	12.4 (3.9)	14.2 (4.0)**	13.9 (4.1)**
Hip extension	22.6 (7.9)	23.7 (7.7)*	24.7 (8.0)**
Hip flexion	23.9 (6.7)	27.0 (6.9)**	28.1 (7.8)**
Reaction time (msecs)	275 (35)	262 (30)**	270 (31)**
Neuromusc control (taps/8s)	30.4 (6.1)	32.9 (5.9)**	32.7 (5.5)**
Sway (mm squares traversed in 30 secs)			
Eyes open (floor)	57 (23)	52 (24)	53 (29)*
Eyes closed (floor)	75 (51)	65 (28)*	70 (37)
Eyes open (foam)	98 (45)	83 (36)*	86 (29)*
Eyes closed (foam)	159 (67)	138 (57)**	148 (64)*
Controls (n = 76)			
Strength (kg force)			
Ankle dorsiflexion	7.7 (2.2)	8.0 (2.1)	8.2 (2.2)
Knee extension	23.8 (8.6)	23.7 (8.1)	23.0 (8.5)
Knee flexion	12.6 (4.4)	12.0 (4.5)	11.7 (4.4)
Hip extension	21.1 (8.3)	20.4 (7.6)	19.7 (7.3)
Hip flexion	24.3 (7.7)	23.9 (7.6)	24.0 (8.2)
Reaction time (msecs)	279 (42)	284 (34)	290 (42)
Neuromusc control (taps/8s)	31.6 (6.4)	31.6 (6.7)	31.7 (5.6)
Sway (mm squares traversed in 30 secs)			
Eyes open (floor)	59 (25)	62 (35)	65 (28)
Eyes closed (floor)	72 (36)	84 (62)	80 (37)
Eyes open (foam)	111 (58)	106 (60)	110 (48)
Eyes closed (foam)	162 (65)	183 (79)	176 (87)

Increases in the tests of strength and neuromuscular control and decreases in the tests of reaction time and sway indicate improvements.
MANOVA Univariate comparisons made with pretest: $^*P < .05$, $^{**}P < .01$.

Table 5. Number and Percentage of Subjects Who Recorded Distinct[†] Improvements in the Physiological Tests at Retest

	Exercisers (n = 75)	Controls (n = 76)
Strength (kg force)		
Ankle dorsiflexion	42 (56.0)*	29 (38.2)
Knee extension	57 (76.0)**	20 (26.3)
Knee flexion	40 (53.3)**	17 (22.4)
Hip extension	35 (46.7)**	19 (25.0)
Hip flexion	49 (65.3)**	21 (27.6)
Reaction time (msecs)	28 (37.3)**	14 (18.4)
Neuromusc control (taps/8 secs)	46 (61.3)*	33 (43.4)
Sway (mm squares traversed in 30 secs)		
Eyes open (floor)	42 (56.0)**	24 (31.6)
Eyes closed (floor)	34 (45.3)**	17 (22.4)
Eyes open (foam)	35 (46.7)	26 (34.2)
Eyes closed (foam)	37 (49.3)	28 (36.8)

[†] Defined as 10% increase in the strength tests, a 5% reduction of reaction time, a 5% increase in neuromuscular control, and a 10% reduction in the sway tests. Comparisons made using chi-square tests for cross-tabulation tables: * $P < .05$, ** $P < .01$.

icant linear contrast ($P < .001$) and a nonsignificant quadratic contrast ($P = .972$) in the multiple analysis of variance test. Improvement was also evident in hip flexion strength (linear contrast significant at $P < .001$) although the quadratic contrast was also significant ($P = .049$), indicating that further improvement was less marked. Figure 1 shows the percentage changes from baseline in the knee and hip muscle strength groups for the exercise and control groups at 22 weeks and 12 months.

Falls

Table 6 shows details of falls frequency and types for the 75 exercisers who complied with the program and 94 control subjects - the 76 who underwent the 12-month retests and an additional 18 who completed the falls follow-up component only (Table 6). When analyzing falls of all types, a similar percentage of exercisers and controls fell in the study year. However, there were notable differences when comparing particular fall types.

A significantly greater percentage of controls cited the causes of their falls to be balance-related, i.e., a loss of balance, legs giving way and "not sure," than did exercisers. There were also trends indicating that fewer exercisers suffered falls within their homes or "nonaccidental" falls in the follow-up year (i.e., falls other than a single trip or slip in

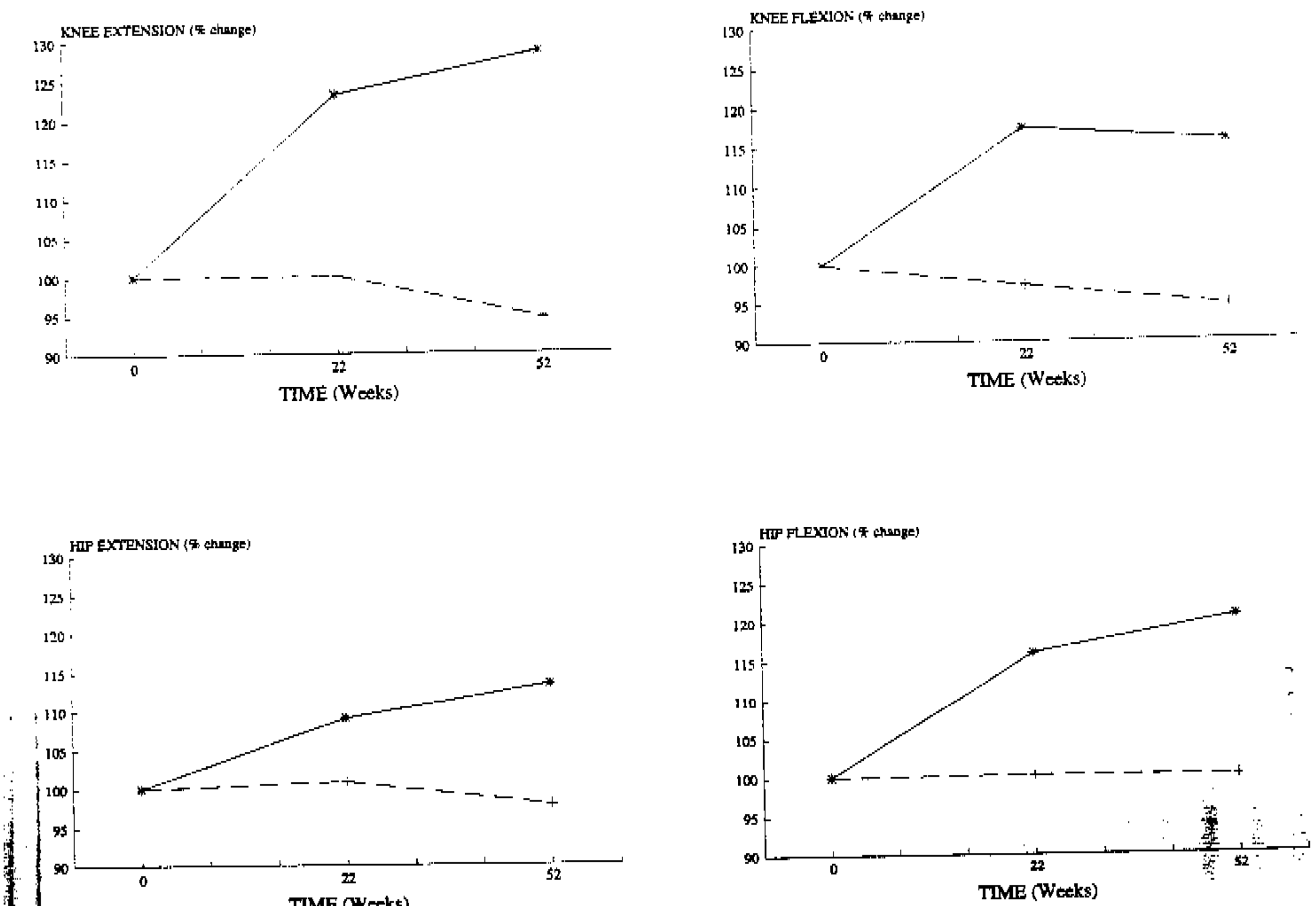

Figure 1. Mean knee and hip muscle strength scores at baseline, 22 weeks, and 12 months. Solid line - exercisers; dashed line - controls.

Table 6. Falls in the Exerciser and Control Groups

Falls Measure	Exercisers n = 75	Controls n = 94	RR (95% CI)*
One or more falls	26 (34.7)	33 (35.1)	0.99 (0.65–1.50)
Two or more falls	8 (10.7)	12 (12.8)	0.84 (0.36–1.94)
Balance falls	4 (5.3)	16 (17.0)	0.31 (0.11–0.90)
Nonaccidental falls	13 (17.3)	23 (24.5)	0.71 (0.39–1.30)
One or more falls inside	7 (9.3)	12 (12.8)	0.73 (0.30–1.77)

* Relative risk statistic compares exercisers (n = 75) with controls (n = 94).

which the subject stated that they would have fallen in the same circumstances if they had been 30 years younger).

Notable trends were also evident between falls frequency and adherence to the exercise program. Exercisers who attended 75% or more of the classes suffered fewer falls (as indicated by all falls measures) than either exercisers who attended less than 75% of the classes or control subjects (Table 7). When compared with falling frequency before the commencement of the study,[10] the incidence of multiple falling in the high adherers group was halved (declining from 12.5% to 6.3%), while the prevalence of multiple falling in the low adherers remained the same (at 14.8%) and was little changed in the controls (13.8% before the trial and 12.8% in the follow-up year). In total, there were 22 falls in the 48 high adherers (45.8/100 subjects) compared with 18 falls in the 27 low adherers (66.6/100 subjects) and 59 falls in the 94 controls (62.8/100 subjects).

DISCUSSION

The findings of this large-scale, randomized, controlled trial of exercise in older people revealed significant improvements in all five lower limb strength measures, reaction time, neuromuscular control, and three of the four sway measures in the exercisers, with no significant changes evident in the control group. Clearly, the program was of sufficient duration and the exercise stimulus sufficiently intensive to result in considerable improvement in sensorimotor function in the exercisers.

The exercise program was found to be safe, with no medical incidents occurring. The subjects found the program enjoyable, which is evident by the high compliance and the very low drop-out rate. Even when including those who discontinued the program because of illness, injury, and death, the dropout rate of only 25% is well below the usual figures reported for such interventions of the duration of the present study.[27] Factors that may have played roles in ensuring that the program was successful included: exercise classes held in venues that were easily accessible; classes run by personnel trained in running such programs for older people; rationale for the study and the assessment measures explained clearly to both exercise and control subjects; and feedback provided to all subjects regarding their performances in the tests at the completion of the program.

It should be noted, however, that one inherent limitation in a study of this type is that the subjects can not be blinded to their "treatment" condition. Thus, the exercise subjects were aware that they were receiving the intervention, and it is possible that part of the improvement noted at retest in this group may have been caused by increased motivation and effort expended in the tests of strength, reaction time, and neuromuscular control. Such a confound, however, is unlikely to have occurred in the sway tests, as these tests do not rely on maximal performance. A second study limitation is the possibility of experimenter bias inasmuch as the investigators who assessed the subjects were not blind to treatment status.

Previous studies have found that exercise can improve muscle strength, although many of these trials have employed heavy resistance training requiring either weights or equipment.[4–8] The findings of the current study show that structured "general" exercise can also improve lower limb muscle strength significantly. The practical implication of this is that older people will be more likely to participate, and remain in, exercise programs that employ enjoyable group activities rather than programs that base the intervention on specific, repetitive muscle group exercises.

The exercise intervention had small effect on reducing sway when subjects were standing on a firm surface but greater effect in the test conditions that stressed stability, that is, the tests undertaken on foam rubber. In previous studies,[23, 28] we have found that measures of lower limb sensation, such as tactile sensitivity, vibration sense, and proprioception, were the best sensorimotor predictors of sway under normal conditions (i.e., when subjects were standing on a firm surface), whereas under more challenging conditions (when subjects were standing on foam rubber), vision, strength and reaction time also played significant roles. It is possible that the improvement in the sway tests undertaken on the foam rubber may have been mediated, at least in part, by concurrent improvements in muscle strength, neuromuscular control, and reaction time. In contrast, it is likely that exercise has little effect on peripheral sensory systems, which may be reflected in similar sway measures on the firm surface in both exercisers and nonexercisers. Complementary measures of stability, such as responses to self-initiated or externally produced perturbations, may also assist in elucidating the mechanisms by which exercise can improve balance control.

The improvement in reaction time in the exercisers is consistent with published studies and supports the suggestion by Rudisill and Toole that older inactive persons can avoid or minimize increases in their central processing time without having had a lifetime of physical activity.[9] The significant

Table 7. Falls in Low Adherer and High Adherer Groups

Falls Measure	Low Adherers n = 27	High Adherers n = 48	RR (95% CI)*
One or more falls	12 (44.4)	14 (29.2)	0.83 (0.49–1.40)
Two or more falls	4 (14.8)	3 (6.3)	0.49 (0.15–1.65)
Balance falls	2 (7.4)	2 (4.2)	0.24 (0.06–1.02)
Nonaccidental falls	7 (25.9)	6 (12.5)	0.51 (0.22–1.17)
One or more falls inside	4 (14.8)	3 (6.3)	0.49 (0.15–1.65)

* Relative risk statistic compares high adherers (n = 48) with controls (n = 94).

improvement in neuromuscular control in the exercisers suggests that this may also be the case for this parameter.

In most measures, the improved performances found in the tests at the study mid-point in the exercisers were maintained at 12 months, and in one test measure, hip flexion strength, the exercisers showed further improvement in the second half of the study year. Performances in reaction time and sway with the eyes closed, however, were intermediate between baseline and mid-point scores. Nonetheless, it appears that exercise may reduce age-related declines in these parameters as apparent progressive functional declines were evident in the controls.

There was no significant difference in the proportion of fallers between the exercise and control subjects. There were, however, certain interesting trends. There was a trend indicating that falls frequency was related to attendance, with the lowest falling rate noted in exercisers who attended 75% or more of the classes. Furthermore, fewer fallers in the exercise group stated that their falls were due to a loss of balance or lower limb weakness than did fallers in the control group, and fewer exercisers suffered nonaccidental falls or falls within their homes - measures that may indicate fewer intrinsic or pattern falls. It is acknowledged, however, that as the subjects were aware of their treatment conditions, the findings relating to fall sub-types should be viewed with caution.

Multiple falling was also less frequent in the exercisers, where a power analysis revealed that group sizes of 200 would have revealed significant differences in multiple falling rates between exercise compliers and controls. A number of recent studies that have attempted to elucidate risk factors for falling have focused on multiple or recurrent falls as their outcome measure.[16,20,29] This measure has been adopted since it has been suggested that identifying factors related to multiple falling may be more important than identifying factors associated with single falls; single falls are less predictable whereas multiple falling may indicate chronic disorders or significant physiological impairment.[29,30] The sizeable reduction in multiple falls frequency among the high exercise adherers suggests that multiple falling may also be a salient outcome measure when examining the effects of interventions such as exercise.

It is clear that a uniform exercise program will not provide a complete intervention for falls prevention, apart from other independent risk factors such as medication use and cognitive impairment; postural control also relies heavily upon sensory inputs, particularly vision and peripheral sensation[23, 28] - physiological systems for which exercise may have little or no therapeutic effect. Dual interventions aimed at improving vision in addition to improving balance and strength through exercise may prove to be more effective in reducing falls. Nevertheless, by improving certain physiological inputs, exercise may assist older persons in compensating for deficits in one or more sensory inputs.

In conclusion, the significantly better performance by the exercise group in the physiological tests after the trial demonstrates that exercise can play an important role in improving stability and related factors in older persons. The high adoption and adherence rates indicate that exercise interventions of this nature may offer an effective health promotion strategy, with potential for improving quality of life and reducing health care costs. The findings also suggest that high adherence to an exercise program may reduce falls frequency. However, further studies are required to conclusively demonstrate that exercise offers an effective means of preventing falls.

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