

Balance and Strength Training in Older Adults: Intervention Gains and Tai Chi Maintenance

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OBJECTIVE: To determine the effect on balance and strength of 3 months of intensive balance and/or weight training followed by 6 months of low intensity Tai Chi training for maintenance of gains.

DESIGN: Randomized control intervention. Four groups in 2 × 2 design: Control, Balance, Strength, Balance + Strength, using blinded testers.

SETTING: Exercise and balance laboratory at University of Connecticut Health Center.

PARTICIPANTS: Subjects were 110 healthy community dwellers (mean age 80) who were free of dementia, neurological disease, and serious cardiovascular or musculoskeletal conditions.

INTERVENTIONS: Short-term training (3 months) occurred 3 times/week (45 minutes Balance and Strength, 90 minutes Balance + Strength). Balance training included equilibrium control exercises on firm and foam surfaces and center-of-pressure biofeedback. Strengthening consisted of lower extremity weight-lifting. All subjects then received long-term group Tai Chi instruction (6 months, 1 hour, 1 time/week).

MEASUREMENTS: Losses of balance during Sensory Organization Testing (LOB), single stance time (SST), voluntary limits of stability (FBOS), summed isokinetic torque of eight lower extremity movements (ISOK), and usual gait velocity (GVU).

RESULTS AND CONCLUSIONS: Balance training meaningfully improved all balance measures by restoring performance to a level analogous to an individual 3 to 10 years younger: LOB = -2.0 ± 0.3 (adjusted paired differences, $P < .005$ ANOVA); SST = 7.0 ± 1.2 sec; and FBOS = $9.0 \pm 2.0\%$ of foot length ($P < .05$). Strengthening increased ISOK by 1.1 ± 0.1 Nm kg⁻¹ ($P < .005$) There was no interaction between balance and strength training. Significant gains per-

sisted after 6 months of Tai Chi, although there was some decrement. *J Am Geriatr Soc* 44:498-506, 1996.

Numerous studies demonstrate that impaired balance and decreased lower extremity strength are important risk factors for the loss of physical function¹ and occurrence of falls in older adults.²⁻⁶ There is a 20 to 40% decrease in strength from the 20s to the 70s.⁷⁻⁹ However, short-term resistance training readily increases knee isokinetic (10-18.5%) and 1-repetition maximum (1RM) strength (107-227%) of older men¹⁰ and women ($174 \pm 31\%$)¹¹ and is well tolerated.^{11,12}

Balance^{13,14} and its neuromuscular foundations^{9,15-20} also deteriorate with age. Although less predictable than strength, balance too has been shown to be responsive to training.²¹⁻²⁴ Unlike strengthening, however, there is no consensus regarding which of the critical elements of motor behavior need to be trained to result in improved balance or what measures of balance validly reflect its complexity and multidimensionality.

A recent review²⁵ of studies about attempts to improve balance in older adults revealed extremes in variability of subject composition, study design, and intervention description. Only 57% of the studies were randomized control trials (RCT); of these, only two screened and excluded subjects using physical examination criteria,^{21,22} and only one utilized blinded testers.²³ A single RCT study evaluated the maintenance of training effects.²⁴ No study combined the features of blinded testing, physical screening, and postintervention training for the maintenance of gains.

One-third of the RCTs included strengthening,^{11,21-23,26-28} but only two^{11,22} had components of progressive resistance training. None employed a factorial design to separate the effects of strengthening from other aspects of the intervention. Very few of the balance interventions had predefined frameworks for training (e.g., sensory organization conditioning²⁴ and vestibular habituation training²⁷) or were described in enough detail to be replicable.

For editorial comment, see p. 599

The present study will examine the roles of intensive (3 times/week for 3 months) balance (B) versus strength (S) versus balance plus strength (B+S) training in improving balance performance, as measured by three diverse measures of challenge to equilibrium: losses of balance (LOB) resulting from attempts to stand on an unstable force platform (senso-

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ry organization testing on a computerized tiltable force platform); maximal voluntary anteroposterior leaning (Functional Base of Support — FBOS); and single leg standing time (SST). Balance training, in turn, emphasized the analogous domains of maintaining balance on foam during visual and perturbational (manual) challenges, extending the limits of sway through visual center-of-gravity feedback, and maintaining stability over reduced areas of support. Strength testing employed isokinetic dynamometry, whereas training consisted of conventional progressive weight lifting with the lower extremities.

In addition to investigating the short-term (3 months) effects of high intensity (3 times/week) balance and/or strength training, this study also explored the subsequent influence of reduced intensity (1 time/week) longer-term (6 months) training on the preservation of gains achieved during the intensive phase. Only one other RCT study evaluated the maintenance effect of low intensity balance training,²⁴ and none have examined strength preservation.

Tai Chi, which has been reported to reduce falls²⁹ in older people, was chosen as a low-intensity (1 time/week) group balance and strength maintenance form of exercise. It consists of slow, graceful, and precise total body movements founded on oriental martial art tenets.³⁰ There are similarities between Tai Chi and portions of the present intensive short-term balance intervention (see Methods). Because Tai Chi is also carried out with a lowered center of gravity (knees and hips held in flexion), resultant knee and hip strengthening may maintain strength gains expected from short-term resistance exercise.

The primary goal of the study was to determine the feasibility and effectiveness of 3 months of high intensity strength and/or balance training in improving balance of older community dwellers free of clinically detectable disease that would affect balance. These subjects were chosen because we felt that the exclusion of subjects with diseases impairing the sensorimotor components of balance would allow us to definitively determine if the balance of older persons was trainable. A secondary objective was to assess whether improvements in balance and strength could be maintained for 6 months through a program of reduced intensity training in the form of weekly Tai Chi classes.

Unlike previous studies, this study incorporated all of the following: (1) a 2 × 2 RCT design to factor out the relative contributions of three months of intensive balance and/or strength training; (2) inclusion-exclusion criteria based on medical history and physical examination; (3) blinded testing; (4) replicable and defined intervention methodology; (5) a reduced intensity 6-month group balance and strength maintenance program (Tai Chi); (6) intermediate measures of intervention efficacy; (7) and multiple balance outcome measures.

METHODS

Subjects and Recruitment

Subjects in this study were recruited as members of the University of Connecticut arm of the FICSIT (Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) trials.³¹ The sampling frame for subject recruitment was a voter registration list of individuals 75 years or older residing in West Hartford, a Hartford suburb adjacent to the School of Medicine. 91.4% of all West Hartford residents of

this age are registered voters.³² We used the following exclusion criteria to limit the study to subjects who could safely undertake the intensive intervention: inability to walk 8 meters without assistance, cancer (metastatic or under active treatment), neurological disease known to impair mobility (e.g., Parkinson's disease, stroke), dementia, defined as a Mini-Mental State Examination (MMSE)³³ score < 24), hip or knee joint replacement, previous hip fracture, cardiovascular disease symptomatic during moderate exertion (attributable to coronary artery disease or congestive heart failure), myocardial infarction within the previous 6 months, poorly controlled hypertension (BP > 166/96 mm Hg), and use of specific medications known to impair balance (e.g., neuroleptics or benzodiazepines) or impair strength (prednisone > 5 mg/day).

Five batches of questionnaire/recruitment letters were mailed during a 15-month period (N = 7191). Six percent (n = 410) of those contacted expressed an interest in attending an orientation session. Of these, 136 were ineligible for reasons of health (see exclusionary criteria above). Before randomization, 164 dropped out, leaving 110 subjects to be randomized (27% of interested responders). This study sample is comparable to other groups of community dwelling participants in exercise studies with regard to age, health, and physical characteristics.²⁹

At the orientation, the study was described, an informed consent was obtained, and the MMSE³³ was administered to each potential subject. The second prerandomization visit included a medical history, screening physical examination, and the completion of questionnaires, including items on depression (CES-D, Center for Epidemiologic Studies, Depression),³⁴ ADLs,³⁵ IADLs,³⁶ status of physical health³⁷ and mobility.⁵ The functional status measures were assessed for the purpose of testing for baseline comparability of intervention groups. In a third session, baseline balance and strength testing were performed, as well as the remainder of the core items included in FICSIT.

At the completion of baseline testing, subjects were randomized to one of four groups through use of a blocked allocation schedule stratified by gender and generated using the Moses-Oakford algorithm.³⁸ The four intervention groups were: Balance (B), Strength (S), Balance + Strength (B+S), and Education Controls (EC). The 3-month intervention program was followed by a 6-month, low-intensity balance and strength maintenance program consisting of weekly Tai Chi training supplemented by brief periods of self-administered home practice.

The control group also participated in the 6-month Tai Chi training phase. This served the dual purpose of allowing us to examine the isolated effects of low-intensity exercise on previously untrained individuals and of offering subjects relegated to the control group an inducement to participate in the study.

Intervention Protocol

Balance Training

Balance training consisted of three 45-minute training sessions per week, with one-on-one instruction. Each session was divided into "platform" (center of pressure biofeedback), and "non-platform" exercises, which were individualized to the subject's ability (Table 1). During both forms of training, subjects were presented with challenges that re-

Table 1. Types of Balance Challenge During Platform and Non-Platform Balance Training at Various Levels of Difficulty

Balance Challenges	Mode of Training ^S	Level of Difficulty		
		Easy	Medium	Hard
Visual conditions	Platform	feedback	blank screen	eyes closed
	Non-platform	eyes open	eyes open	eyes closed
Area of support	Platform	feet apart	together, 1/2tan, tan	1-leg stand
	Non-platform	feet apart	together, 1/2tan, tan	1-leg stand
Surface conditions	Platform [†]	stable	compliant tilts	random tilts
	Non-platform	floor	thin foam	thick foam
Manual push/pull	Platform	none	gentle/slow	hard/fast
	Non-platform	none	gentle/slow	hard/fast
Limits of* [†] sway	Platform	<50%	50-74%	75-100%
	Non-platform	small sway	medium sway	large sway

*Sway in both modes could be linear or curvilinear, and in forward, backward, sideway, and oblique directions.

[†]Sway speed was varied, and was more systematically practiced in the platform mode.

^{||}Visual feedback was not possible during platform tilts in the frontal plane.

[§]Seated balancing on therapeutic ball was only performed in non-platform mode, without foam.

[¶]Training while walking excluded manual perturbations; speed and direction of progression were varied.

flected real-life demands on balance. A daily log of performance was maintained, and subjects were informed of their progress. Safety, which was a primary consideration, was achieved through use of a harness and close guarding. A performance log was kept, and subjects were informed of their progress regularly.

Non-platform training (Table 1) was performed while standing and while sitting on a 22-inch therapeutic ball, using combinations of the following conditions: (1) eyes open or closed, (2) normal or reduced area of foot support, (3) on foam or floor, (4) with or without manual perturbations (anteriorly or posteriorly directed pushes), and (5) during maximal leaning in all directions. Gait training occurred on foam (5 or 8 inch 10-30 polyurethane) or on a narrow beam (3.5 inches wide \times 0.75 inch high) while varying direction and visual conditions. Special emphasis was placed on keeping the trunk vertical and maintaining an imaginary line between the iliac crests parallel to the ground. Mirrors, tactile cues, and muscle self-palpation were used as aids to motor learning.

Platform training (Table 1) was performed while standing on a PRO BalanceMaster (NeuroCom Int'l, Clackamas, OR). An eye-level video monitor displayed a cursor that represented the subject's center of pressure (COP). Subjects were asked to move the cursor to targets on the periphery of the screen by leaning without moving their feet. Targets could be placed to encourage maximal leaning (limits of sway) in any direction while holding the trunk vertical.

As in non-platform training, the task conditions also entailed manipulation of visual, foot, surface, and perturbation conditions, with combinations individualized to a subject's abilities. Platform rotations, simulating foam-like conditions, were delivered in the sagittal or frontal planes in either "random" (unexpected change of amplitude and direction of tilt) or "compliant" ("viscous" response to sway followed by "elastic" rebound tilts) modes. Progress in training was monitored at baseline, 5, 9, and 13 weeks by determining how many of eight peripherally placed targets a subject could touch with the COP position cursor during eight 4-second trials (8T).

Strength Training

Groups of two to three subjects attended three supervised, 45-minute exercise sessions per week. Static stretching of muscle groups was performed before resistive exercises to reduce the risk of muscle/tendon injury. Resistance training employed a combination of sandbags (prone-lying hip extension, side-lying hip abduction, and prone-lying knee flexion) and resistive machines (knee extension - Titan Exercise Equipment, Carrollton, TX; ankle dorsiflexion - Ankleciser, Feeco Inc, Green Bay, WI). Repetitive lifting of body weight (heel rises) was used for ankle plantar flexors. Subjects performed two sets of unilateral resistive exercises, to both left and right muscle groups, at a resistance that permitted at least eight lifts with full range of motion and good form.

Sandbag/body weight resistive training was designed to provide the greatest resistance at the range of motion used in functional activities. To set the training resistance for individual muscles, measurements of 1RM were performed at baseline, 5, 9, and 13 weeks and the subsequent resistance set at 70 to 75% of 1RM. In the intervening weeks, resistance was increased in 0.4 to 1.2-kg increments whenever a subject was able to complete more than 13 repetitions with good form. For knee extension and ankle dorsiflexion, periodic one-repetition maximum (1RM) tests were performed at weeks 1, 5, 9 and 13. These served two objectives: (1) to establish periodic 75% of 1RM loading standards for resistive training, and (2) to be able to track the progress of strength increases throughout the intervention on a loading system identical to the one used during training, but consisting of a measure different from the isokinetic outcome variable (see Outcome Measures).

One-repetition maxima were established by asking a subject to lift a load through a full range of motion (90° knee extension; 30° dorsiflexion). Perceived effort level determined the amount of incremental loading (easy/moderate = 5 lbs., hard/very hard = 2.5 lbs.), with 1-minute rests between attempts. The highest load that could be successfully raised through a full range was designated the 1RM.³⁹

Balance + Strength Training

Subjects in the B+S group completed both 45 minutes of balance and 45 minutes of resistance training three times per

week. Balance exercises were always performed first, with a 5-minute rest between the balance and resistance sessions.

Educational Control Group

Educational control group subjects were encouraged to continue their usual activities. All four groups participated in an educational component consisting of five 90-minute sessions dealing with fall prevention and stress management.

Maintenance Phase

Subjects in all four groups participated in the maintenance phase. Tai Chi Chuan was chosen for the 26-week maintenance phase because it is a safe and highly structured training technique that utilizes biomechanically sound principles of movement and posture.⁴⁰ The goal of Tai Chi is to develop an enhanced sensibility of the pelvis and trunk as the frame of reference for movement.³⁰ Instruction in body awareness, relaxation, imagery, and breathing are integral aspects of the training. Subjects attended weekly (1 hour) group training sessions and were asked to practice twice per week (5-15 minutes/session) at home and to maintain a practice log. Group training consisted of highly structured exercises utilizing the Chang approach, which emphasizes very slow weight shifts, steps, and turns while maintaining a lowered center of gravity, i.e., with the knees and hips kept in mild to moderate flexion. Movements were performed using a combination of specific: (1) body alignments (perpendicular torso, horizontal pelvis, axially extended neck), (2) orientations (head, torso and pelvis directed at frames of reference in the room), (3) weight shifts (while center of gravity is maintained in a horizontal plane), and (4) directional changes (rotation about the hips rather than the neck or trunk), as delineated by Man-ching and Smith.²⁹ Subjects received concurrent instructions on body awareness, relaxation, imagery and breathing.

Adverse Effects Monitoring

At each exercise session, subjects were questioned about the presence of musculoskeletal symptoms. Modifications in the individual's training program were based on a geriatrician's evaluation of the symptoms. These usually involved a 1-week hiatus from the resistance exercise, during which time static stretch exercises were performed. There was slow reintroduction of resistance with increased concentration on correct form. The exercise trainers were instructed to be alert for the emergence of symptoms of angina and shortness of breath. Subjects with histories of hypertension were given weekly blood pressure spot-checks.

Subject Retention

Subjects were considered drop-outs if they failed to return for repeat testing of endpoint measures or if they withdrew during the intervention. All subjects who stopped attending exercise or discussion sessions were contacted and encouraged to return for postintervention testing.

Outcome Measures

Outcome measures were assessed at baseline (BA), postintervention (PI, 3 months), and postmaintenance (PM, 9 months). Testing was performed by three physical therapists who were uninvolved in other aspects of the study, and "blinded" to the intervention group assignment.

Losses of Balance During Sensory Organization Test

Subjects were tested on a computerized posturography platform (EquiTest, Clackamas, OR) with tests of motor and sensory aspects of balance. The protocol for the platform, which has been described previously,⁴¹ consisted, in part, of the sensory organization test (SOT), which measures a subject's ability to utilize visual, tactile-proprioceptive, and vestibular inputs to coordinate motor responses appropriate to unstable support surface conditions. Loss of balance occurred when a subject took a step or received support from the examiner. The number of LOBs that occurred during the three unstable platform conditions (normal, absent, and inaccurate vision) was a primary outcome measure for balance. This measure varies with age⁴² and shows concurrent validity with one-legged stance time, gait velocity, and isokinetic strength.⁴³

Functional Base of Support

Two additional 20-second trials on a stable platform surface were used to measure FBOS. Functional base of support, which has been described previously,⁴⁴ is the anterior-posterior (A-P) distance between the mean COP positions measured during 5 seconds of maximal forward and 5 seconds of backward leaning, divided by foot-length. Functional Base of Support is sensitive to aging, decreasing from 60 to 70% of foot-length in people aged 20 to 60, to 44% of foot length in those older than age 60.⁴⁴ It is significantly correlated with measures of balance, gait velocity, ankle strength, and step-length⁴⁵ and shows a test-retest intraclass correlation coefficient of .80.⁴³ The best FBOS of the two trials was selected.

Single Stance Time

Single stance time is one of the most challenging gauges of stability while standing on a narrow area of support. It has been the most frequently used measure of balance in physical training studies involving older adults²⁵ and is inversely associated with aging,⁴⁶ even in people 70 to 100 years old and in optimal health.⁴⁷ Two trials each of semi-tandem, tandem, and single stance were performed barefoot and with arms crossed. The longer of the two trials was used. The maximum time recorded was 30 seconds. Because almost all subjects completed 30 seconds of semi-tandem and tandem stance, only the single stance time (SST) is reported here.

Muscle Strength

Summed isokinetic peak joint moment at the three lower extremity joints was the primary outcome variable for strength. Isokinetic strength was measured on a Cybex 340 isokinetic dynamometer on the right limb at an angular velocity of 30° s⁻¹ at the hip and ankle and 60° s⁻¹ at the knee (for details regarding positioning, stabilization and test performance, refer to Judge et al.³⁹). Flexion and extension were measured at all joints, and abduction/adduction were measured at the hip. ISOK is the sum of the peak joint moments for each of the eight movements and is reported in Newton meters per kilogram of body weight (Nm/kg). This measure summarizes muscle forces controlling the major movements of the hip, knee, and ankle at velocities similar to those occurring during functional activities.

Usual Gait Velocity

Gait velocity is easily measured, decreases with aging, and is closely correlated with balance, function,⁴⁸ and falls.⁴⁹ It also shows strong inter- (0.93) and intra-tester (0.89) correlations,¹⁸ and is sensitive to change.²³ GVU was measured over an 8-m course, using photo-electric timing devices, at usual pace. The mean of three attempts is reported.

Statistical Analysis

Baseline demographic and functional status measures were compared using analysis of variance for continuous variables and chi-square for categorical variables. Trends in intermediate measures of balance and strength across the active intervention phase were evaluated with repeated measures analysis of variance.

To determine whether any of the interventions resulted in improvements from baseline, compared with the control group, analysis of covariance models were constructed in which the dependent variable was change from baseline to postintervention (calculated as postintervention value minus baseline value), and the main effect of interest was group (a categorical variable with four levels: balance, strength, balance + strength, or control). The models included covariates for baseline age, gender, and a first order interaction term for group and gender. Within the analysis of covariance model, specific contrasts were constructed for comparisons of each intervention group with the control group. Thus, for each outcome studied, three separate contrasts were constructed. In order to ensure an overall alpha level of .05, each F-test was evaluated at the $P \leq .05/3$ level ($P < .02$).

To determine whether function was preserved within each group during the maintenance phase of the study, analysis of covariance models were constructed as described above, with the dependent variable defined as the difference between the postmaintenance and postintervention values. Within each group, the adjusted mean change and its standard error from the model were used to compute a *t* test of

whether the within group change differed significantly from zero.

The overall effects of the balance, strength, and balance + strength interventions on outcomes were evaluated in analysis of covariance models that took into account the 2×2 factorial design of the study. For each outcome, the dependent variable was specified as change from baseline to either postintervention or postmaintenance. The model included main effects for balance and strength (represented by dichotomous variables 1 = yes, 0 = no) and a term for the first order interaction of balance and strength training. The main effects and interaction terms were evaluated at a .05 alpha level.

Given the minimum group size for each outcome studied (LOB $n = 26$; FBOS $n = 16$; SST $n = 19$; ISOK $n = 21$; GVU $n = 24$), the study has greater than 80% power to detect between group differences in mean changes of the following sizes: LOB 0.32 falls, FBOS 2% of foot-length, SST 1.5 seconds, ISOK 0.2 Nm/Kg, GVU 0.025 m/sec.

RESULTS

Subjects

The study comprised 110 randomized subjects (mean age = 79 ± 5 years, 58% male) who were well educated (at least 3 years of college) and relatively healthy, with the majority rating their health as good to excellent. The Sickness Impact Profile subscale scores showed low perceived problems with mobility and ambulation. A small number of subjects ($n = 18$) had difficulty with IADLs. The four groups were comparable on demographic and functional measures, as shown in Table 2.

Compliance, Side Effects, and Retention

Musculoskeletal complaints developed in 10 of 55 subjects in the S and B+S groups. The symptoms consisted of hamstring or quadriceps cramping or tenderness (6 subjects), low back pain, knee pain, and trochanteric bursitis. With lowering of the resistance and other minor modifications of

Table 2. Baseline Characteristics by Intervention Group*

Intervention Group	Mean \pm SD			
	Control	Balance	Strength	Balance and Strength
n	27	28	28	27
Age (years)	80.6 \pm 4.5	78.9 \pm 2.8	80.0 \pm 4.1	79.7 \pm 4.1
Male n (%)	16 (59)	16 (57)	18 (64)	14 (52)
Education (years)	15.0 \pm 3.5	15.1 \pm 2.6	14.8 \pm 3.1	15.3 \pm 3.2
Health Status n (%)				
Excellent/Very Good	11 (42)	12 (44)	12 (48)	13 (52)
Good/Fair	15 (58)	15 (56)	13 (52)	12 (48)
MMSE (0-30) ^{†‡}	28.8 \pm 1.7	28.8 \pm 1.0	28.0 \pm 1.5	28.3 \pm 1.5
CESD score (20-60) ^{†‡}	25.5 \pm 5.8	27.4 \pm 4.8	26.2 \pm 7.1	28.9 \pm 8.6
SUM IADL (0-24) ^{†§}	23.2 \pm 1.5	23.7 \pm 0.8	23.7 \pm 1.1	23.9 \pm 0.4
SUM SIP ambulation (0-80.4) ^{†§}	3.8 \pm 5.4	4.6 \pm 6.9	5.9 \pm 8.8	9.7 \pm 11.8
SUM SIP mobility (0-71.9) ^{†§}	2.3 \pm 5.9	1.3 \pm 1.2	1.9 \pm 5.3	2.8 \pm 5.0
Fall in prior year n (%)	7 (27)	9 (33)	8 (31)	5 (20)

*Overall group differences on demographic and functional measures in table, $P \geq 0.10$.

[†]Median \pm SD.

[‡]Highest score—no impairment.

[§]Lowest score—no perceived impairment.

their training regimen, all subjects continued to participate. One of the 56 subjects in the balance intervention developed symptoms related to the intervention that did not prevent completing the intervention. No serious injuries were noted in either the strength or balance trained groups. Complaints were evenly distributed throughout the intervention period.

Attendance at the intervention sessions was $B = 74 \pm 26\%$, $S = 82 \pm 21\%$, $B+S = 82 \pm 16\%$. There was nearly perfect attendance by all four groups at education classes. Ninety-three percent of the subjects performed all of the assigned resistance exercises. The other 7% of subjects had occasional musculoskeletal complaints, either during or between exercise sessions. When pain was present, an exercise was either eliminated or the number of sets, repetitions, or resistance was reduced. Ninety-nine percent of the subjects in the balance groups were able to participate in all of the exercises.

Attendance at the 1-hour/week Tai Chi class sessions during the 6-month maintenance phase was moderately good, with subjects attending a mean of 72% of the sessions. Although some subjects practiced regularly at home (2-3 times/week), most home practice was infrequent and inconsistent, and many subjects preferred performing Tai Chi in a group and under supervision.

Of the 110 subjects randomized, 106 returned for PI balance testing on the posturography platform, yielding a retention rate of 96%. Ninety-eight subjects had isokinetic testing, and 96 subjects had 1RM measures, resulting in a retention rate of 89%. Complete isokinetic data were obtained from 92 subjects at postintervention testing; four subjects did not perform one or more joint movements. SST and FBOS were balance measures that were added after randomization of the third group of subjects and were obtained in 77 and 69 of the subjects, respectively.

Progress of the Intervention

Balance and strength groups demonstrated progressive improvement resulting in more than a 5-fold increase in 8T and a 34% increase in 1RM. The linear trends across time for 8T and knee extension 1RM were significant ($P = .0001$, repeated measures ANOVA).

Effects on Balance, Strength, and Gait

Table 3 displays the mean values for outcome measures assessed at baseline (BA) and postintervention (PI) and the mean changes from baseline for each group, adjusted for baseline age and gender. The occurrence of LOB during the SOT decreased for the B group, and this change was signifi-

Table 3. Balance, Strength and Functional Outcome Measures at Baseline, Postintervention and Postmaintenance (Means \pm SE)

Group	N ₁ *	Baseline (BA)	Post-Intervention (PI)	N ₂ *	Postmaintenance (PM)	Adjusted Mean Change [†] (PI-BA)	Adjusted Mean Change [†] (PM-PI)
Loss of Balance During Sensory Organization Test (LOB)							
Control	26	3.1 \pm 0.5	2.5 \pm 0.5	23	2.1 \pm 0.5	-0.6 \pm 0.4	-0.5 \pm 0.3
Balance	27	3.6 \pm 0.5	1.4 \pm 0.3	24	1.0 \pm 0.2	-2.1 \pm 0.4 [‡]	-0.1 \pm 0.3
Strength	26	3.7 \pm 0.6	2.1 \pm 0.4	19	2.0 \pm 0.6	-1.6 \pm 0.4	0.1 \pm 0.4
Bal. & Strength	27	3.6 \pm 0.5	1.9 \pm 0.4	20	1.9 \pm 0.5	-1.7 \pm 0.4	0.1 \pm 0.3
Functional Base of Support—FBOS (proportion of foot length)							
Control	16	0.40 \pm .03	0.40 \pm .03	15	0.37 \pm .03	0.00 \pm .02	-0.03 \pm .02 [§]
Balance	19	0.44 \pm .03	0.52 \pm .02	18	0.45 \pm .02	0.08 \pm .02 [‡]	-0.06 \pm .02 [§]
Strength	18	0.38 \pm .03	0.39 \pm .03	12	0.37 \pm .04	0.01 \pm .02	-0.02 \pm .02
Bal. & Strength	16	0.40 \pm .02	0.49 \pm .01	11	0.46 \pm .02	0.09 \pm .02 [‡]	-0.04 \pm .02 [§]
Single Stance Time—SST (Seconds)							
Control	19	10.4 \pm 2.5	9.4 \pm 2.0	18	10.2 \pm 2.4	-0.7 \pm 1.7	0.9 \pm 2.0
Balance	20	12.2 \pm 2.7	16.6 \pm 2.4	19	13.7 \pm 2.6	4.7 \pm 1.6 [‡]	-4.3 \pm 2.0 [§]
Strength	19	9.1 \pm 2.3	10.0 \pm 2.5	13	9.3 \pm 2.7	0.5 \pm 1.7	-1.7 \pm 2.3
Bal. & Strength	19	5.4 \pm 0.9	15.1 \pm 2.5	15	13.0 \pm 3.0	9.0 \pm 1.7 [‡]	-1.0 \pm 2.1
Summed Lower Extremity Isokinetic Strength—ISOK (Newton Meters/kg)							
Control	23	6.9 \pm 0.5	6.9 \pm 0.4	18	6.9 \pm 0.5	-0.1 \pm 0.2	-0.1 \pm 0.2
Balance	21	8.0 \pm 0.4	8.1 \pm 0.4	20	8.3 \pm 0.5	0.1 \pm 0.2	0.1 \pm 0.2
Strength	22	6.5 \pm 0.5	8.0 \pm 0.8	15	8.0 \pm 0.8	0.8 \pm 0.2 [‡]	-0.2 \pm 0.3
Bal. & Strength	25	6.8 \pm 0.4	8.0 \pm 0.5	17	7.5 \pm 0.5	1.2 \pm 0.2 [‡]	-0.4 \pm 0.2
Usual Gait Velocity (Meters/Second)							
Control	26	1.08 \pm .04	1.14 \pm .03	23	1.12 \pm .04	0.03 \pm .03	-0.02 \pm .04
Balance	24	1.14 \pm .04	1.18 \pm .04	22	1.18 \pm .04	-0.02 \pm .03	0.02 \pm .04
Strength	25	1.08 \pm .04	1.17 \pm .04	19	1.17 \pm .05	0.08 \pm .03	-0.05 \pm .04
Bal. & Strength	27	1.12 \pm .04	1.09 \pm .04	21	1.19 \pm .04	-0.05 \pm .03	0.08 \pm .04 [§]

*Number (N) for paired comparisons; PI to baseline = N₁, PI to PM = N₂.

[†]Adjusted mean change from ANOVA model, adjusted for gender, baseline age, and gender*baseline age.

[‡]Mean change for group significantly different than that for controls at the $P < .05/3 = 0.02$ level.

[§]Within group adjusted mean change, $P < .05$.

cantly greater than that observed in the EC group. The B+S and S groups also showed improvements (decreases in LOB), although in both instances the changes were not significantly different when compared with EC. Similarly, significant improvements in SST between BA and PI were observed in both the B and B+S groups.

Isokinetic strength was the primary outcome measure for strength. The resistance trained groups (S and B+S) achieved meaningful improvements in peak joint moment in all joint movements trained with the exception of hip abduction and ankle dorsiflexion ($P \leq .015$). Knee extension moment increased 25% (9–41, 95% CI) in S and 23% (7–39, 95% CI) in B+S; hip extension increased 18% (4–32, 95% CI) in S and 24% (10–38, 95% CI) in B+S. Ankle plantar flexion increased 23% (11–35, 95% CI) in S and 19% (7–31, 95% CI) in B+S. Hip abduction moment increased only in B+S, by 26% (12–40, 95% CI). The summary measure of lower extremity strength increased significantly in both S (14%) and B+S (19%) groups, compared with EC (Table 3).

Compared with the EC group, GVU in the B+S group decreased significantly between BA and PI, although the mean change was quite small. GVU changes in other groups were not significantly different from EC (Table 3).

Table 3 also displays mean changes during the maintenance phase, defined as PM minus PI paired differences (PM-PI), adjusted for baseline age and gender. There was no significant change in LOB in any of the groups after the maintenance phase. Significant decays in FBOS were seen after 6 months of Tai Chi for the EC, B, and BS groups. The notable gains of the B and BS groups after the intervention were either partially (BS) or totally (B) lost following Tai Chi. The 3-month SST improvements of B reverted significantly back toward baseline values after Tai Chi, whereas the gains seen in BS were retained. Short-term ISOK gains of both strength-trained groups were preserved. Although GVU increased significantly in the BS group following the maintenance phase, the numerical increases were small.

Table 4 displays the results of analyses of covariance models from the main effects of balance and strength training

on change from BA to PI and PM. Because the interaction between balance and strength training was not statistically significant for any of the outcomes, only the main effects are presented in the table. The effects of balance and strength training on gains from BA to either PI or PM were similar although the changes to PM were not as large. Balance training resulted in significant improvements over BA in all of the balance outcome measures, both at PI and PM. Similarly, strength training resulted in increased lower extremity strength both at PI and PM compared with BA. Strength training resulted in increased SST at both PI and PM, although the effect was statistically significant only at PI. Balance training was associated with significantly decreased GVU at PI and PM; however, the effects were quite small (respectively, -0.03 m/sec, and -0.05 m/sec).

DISCUSSION

The balance intervention improved three aspects of balance function (LOB, FBOS, and SST). These outcomes represent measures of dynamic balance (LOB), limits of stability control (FBOS) and stability on a narrow base (SST). Only two previous studies employed more than one of these measures of balance (sensory organization and SST).^{24,26} Resistance training increased ISOK as well as SST. Finally, the Tai Chi maintenance program sustained improvements in balance and strength for 6 months after the intervention.

Intermediate Measures

We charted the progress of the intervention with 1RM and 8T, measures which were directly trained. It is thus not surprising that the changes in 1RM and 8T were greater than those observed in outcome measures that were not directly trained. Specifically, 8T increased more than fivefold during the intervention, which was much greater than the change noted in any of the balance outcome measures. Similarly, knee extension 1RM increased 34%, whereas the isokinetic moment rose only 25%. The upward slope of the 1RM and 8T data suggest the likelihood that a longer intervention

Table 4. Main Effects of Balance and Strength Training on Outcome Measures* (Adjusted Mean Change \pm SE)

Outcome Measure	Postintervention-Baseline				Postmaintenance-Baseline			
	Balance Training		Strength Training		Balance Training		Strength Training	
	Yes	No	Yes	No	Yes	No	Yes	No
LOB	-2.0 \pm 0.3 [†]	-1.1 \pm 0.3	-1.6 \pm 0.3	-1.4 \pm 0.3	-2.1 \pm 0.3 [†]	-1.0 \pm 0.3	-1.4 \pm 0.4	-1.7 \pm 0.3
(N)	(54)	(52)	(53)	(53)	(44)	(42)	(39)	(39)
FBOS	0.09 \pm 0.02 [‡]	0.006 \pm 0.02	0.05 \pm 0.02	0.04 \pm 0.02	.02 \pm .01 [†]	-0.03 \pm 0.01	0.004 \pm 0.02	-0.01 \pm 0.01
(N)	(35)	(34)	(34)	(35)	(29)	(27)	(23)	(33)
SST	7.0 \pm 1.2 [‡]	-0.08 \pm 1.2	5.3 \pm 1.2 [†]	1.7 \pm 1.2	4.7 \pm 1.8 [†]	-1.5 \pm 1.9	3.1 \pm 2.0	0.1 \pm 1.7
(N)	(39)	(38)	(38)	(39)	(34)	(31)	(28)	(37)
ISOK	0.7 \pm 0.1	0.4 \pm 0.1	1.1 \pm 0.1 [‡]	0.01 \pm 0.1	0.6 \pm 0.2	0.4 \pm 0.2	0.9 \pm 0.2 [‡]	0.06 \pm 0.2
(N)	(46)	(45)	(47)	(44)	(37)	(33)	(32)	(38)
Usual gait Velocity	-0.03 \pm 0.02 [†]	0.05 \pm 0.02	0.01 \pm 0.02	0.01 \pm 0.02	-0.05 \pm 0.02 [†]	0.04 \pm 0.02	-0.01 \pm 0.02	-0.002 \pm 0.02
(N)	(51)	(51)	(52)	(50)	(43)	(42)	(40)	(45)

Least square means from ANOVA model with main effects for balance training (yes/no), strength training (yes/no), the interaction of balance strength, and covariates for baseline age and gender.

[†]P value for main effect $\leq .005$.

[‡]P value for main effect $\leq .05$.

would have resulted in additional improvements in these measures.

Short-Term Effects on Balance, Strength, and Gait

The manipulation of sensory inputs during the SOT results in measures (peak AP sway, number of losses of balance) that have been shown to be sensitive indicators of balance change⁵⁰ and frailty^{14,51} in older adults. The magnitude of improvement in LOB score produced by the balance intervention in the current study is comparable to the normal loss of LOB performance encountered in the age span of 78 to 81.⁴³

Single leg standing time, which is the most commonly utilized measure of balance, is correlated with other measures of physical performance.^{52,53} The improved SST observed as a result of the intervention is comparable to the decline in this measure occurring during the seventh to eighth decade in a cross sectional study.⁵⁴

Functional base of support also improved significantly in response to the balance intervention. Although this is the first time this measure has been used for assessing outcome, it has been used previously as a measure of the limits of sway.^{44,55} The improvement in FBOS that occurred as a result of the intervention is comparable to the cross-sectional change across a 10-year timespan in persons older than 60.⁴⁴

The balance intervention improved three outcome measures representing a spectrum of balance function. The improvements were meaningful when compared with declines observed with age,^{42-44,46,50} thus suggesting that balance of healthy 75 to 90-year-old people, if trained, may be sufficiently plastic to recoup losses that would otherwise be considered age-related.

The training groups demonstrated minimal overlap in the balance and strength outcome measures, suggesting that there is task-specificity associated with each exercise mode.⁵⁶ Thus, subjects who participated in balance training improved on all balance measures, but not in strength. Similarly, resistance training resulted in a 20% improvement in strength. Moreover, there was also an increase in one balance measure — SST. We are uncertain why SST is more sensitive to the change in lower extremity strength than the two other balance measures. It is possible that the increases in hip abductor strength that were seen in this intervention³⁹ translated to better pelvic control of body weight during one-legged standing,⁵⁷ and/or that the heel-rises performed while standing on one leg (plantar-flexor strengthening) may have improved balance over a narrowed base.

Use of our exclusionary criteria eliminated potential subjects with diseases that compromise balance and thus resulted in a sample that was functionally independent, relatively healthy, and had adequate lower extremity strength at baseline. In two studies using subjects who walked more slowly and were weaker than those in this study, resistance training¹¹ and a combined strength and balance intervention⁵⁸ resulted in increased gait velocity. We conclude that our interventions did not increase gait velocity because even at baseline the strength and balance of our subjects was adequate for gait. Similarly, our strength intervention did not produce changes in all balance measures because strength of the subjects at baseline may have already been sufficient for adequate balance in several balance tasks.

Maintenance of Balance and Strength Gains

Following a Tai Chi maintenance program, a portion of the balance improvements noted in the balance-trained groups was lost, although balance at PM was still significantly better than at BA. The strength-trained group maintained much of the strength improvement attained at PI. The small but significant decrease in GVU at PM in balance-trained groups may have been influenced by the deliberate slowness of the Tai Chi movements. Preservation of balance and strength gains for 6 months was encouraging in view of the low intensity of the Tai Chi training.

CONCLUSION

This study demonstrated that relatively healthy older persons can realize meaningful short-term gains in balance and strength by means of a high-intensity, laboratory-based, training program and can maintain those gains to a lesser extent through a low-intensity maintenance program of Tai Chi practice. A maintenance program of balance and strength exercises rather than Tai Chi might have been more effective and should be tested.

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