Effects of Resistive and Balance Exercises on Isokinetic Strength in Older Persons

James O. Judge, Robert H. Whipple,† and Leslie I. Wolfson†*

OBJECTIVE: To determine the safety and efficacy of 3 months of resistive training of multiple lower extremity muscle groups compared with balance training in persons over 75 years.

DESIGN: Randomized 3-month clinical trial. Subjects (n = 110, mean age 80) were randomized to 4 groups in a 2 x 2 design (control, resistive, balance, combined resistive/balance).

INTERVENTIONS: Resistive training involved knee extension and flexion, hip abduction and extension, and plantar and dorsiflexion using simple resistive machines and sandbags. Balance training consisted of exercises to improve postural control. The control group attended 5 health-related discussion sessions.

MEASUREMENTS: Summed isokinetic moments (N m) of 8 leg movements: hip, knee and ankle flexion/extension, and hip abduction/adduction. Secondary outcomes were gait velocity and chair rise time.

MAIN RESULTS: Summed peak moment increased in both resistive exercise-trained groups (13% increase in the resistive group and 21% in the combined training group, $P < 0.001$). The effect of resistance training was significant (MANOVA F = 21.1, $P < 0.001$), but balance training did not improve strength, and there was no interaction (positive or negative) between balance and resistive training. Maximal gait velocity and chair rise time did not improve. Eleven subjects (20%) had musculoskeletal complaints related to resistive training, but all were able to complete the program with modifications.

CONCLUSION: Resistive training using simple equipment is an effective and acceptable method to increase overall leg strength in older persons. Resistive or balance training did not improve maximal gait velocity or chair rise time in this sample of relatively healthy older persons. J Am Geriatr Soc 42:937–946, 1994.

From the *Travelers Center on Aging, University of Connecticut Health Center, and the †Department of Neurology, University of Connecticut Health Center, Farmington, Connecticut.

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Address correspondence to James O. Judge, MD, Travelers Center on Aging, University of Connecticut Health Center, Farmington, CT 06030–5215.

Declines in muscle strength in older persons are often ignored until weakness prevents performance of functional tasks or contributes to a fall. Muscle mass is lost at a rate of 0.5% to 1.0% annually in women and men over 60 years,[1, 2] and muscle strength loss varies from 20 to 40% from the third to the eighth decades,[3–5] and may be even greater in the eighth decade.[6] Weakness is due to loss of muscle mass and contractility (force/cm^2 of muscle cross section).[7–9] muscle strength predicts functional status,[9, 10] gait velocity and step length,[11, 12] and muscle weakness is a risk factor for falls.[13, 14] Vigorous physical activity is associated with maintaining muscle strength, mass, and contractility.[15, 16] Lack of usual physical activity increases the risk for future functional loss, after correcting for the effect of chronic medical conditions.[17, 18] Exercise strategies that can reverse the age-associated decline in muscle force have the potential to reduce or delay the proportion of functional dependence[10] and falls that are caused by muscle weakness.[13, 14]

While many studies have demonstrated large increases in muscle strength after training 1 or 2 joint movements,[1, 19, 20] few studies have tested the effects of resistive training of multiple lower extremity muscle groups. As most functional activities require the coordinated contraction of several muscle groups,[21, 22] it is likely that improving or maintaining functional status will require training multiple joint movements. One resistive machine intervention trained 7 lower extremity movements in women (mean age of 69), and maximal lift (1 RM) increases ranged from 28 to 105%, without injury.[23] Six months of heavy resistive training of upper and lower body exercises in endurance-trained women (mean age 67) was well tolerated and demonstrated small but significant improvements in lower extremity strength gains compared with controls as well as much greater gains in upper extremity strength.[24]

There have been no studies using relatively inexpensive equipment that have been effective in increasing the overall strength of the leg. The general purpose of the present report was to test the safety and usefulness of resistive training of multiple muscle groups of the lower extremity compared with nonresistive exercise training (balance exercises) or a control intervention of health education sessions in community-dwelling persons over 75 years of age. If a relatively "low tech" program were shown to be an effective method for increasing overall lower extremity muscle strength, such a program could serve as a prototype for community-based interventions designed to reduce functional declines due to muscle weakness.

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The specific purpose of the present study was to determine if a resistive training program using sandbag weights and inexpensive resistive machines would improve overall leg strength (summed peak joint moments during 8 isokinetic movements). Secondary aims were to determine (1) the injury rate and acceptability of training multiple muscle groups in a training session in older persons and (2) the effect of training on 2 physical performance measures—gait velocity and time to rise from a chair. Balance outcome will be reported in a future manuscript.

METHODS

A full description of the recruitment plan and baseline characteristics of the subjects has been published.[25] This report is part of the National Institutes on Aging program: Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT), which tested the effects of different intervention strategies on physical performance or falls in community-dwelling and nursing home subjects.[26] This report presents findings from the acute intervention phase of the University of Connecticut site-specific intervention (UCONN FICSIT).

Subjects

Using a voter registration list of individuals 75 years and above residing in West Hartford (Hartford suburb adjacent to the University of Connecticut School of Medicine), 7191 recruitment letters were mailed to potential subjects. Of the 410 persons who expressed interest in the study, 136 did not meet inclusion criteria, and 164 decided not to participate or did not complete baseline screening tests. All subjects had a complete medical history, functional status questionnaire,[27] and a targeted physical examination that focused on cardiovascular, neurologic, and orthopedic diseases. Inclusion criteria were age 75 years or greater, the ability to walk without an assistive device for 8 meters, and Folstein Mini-Mental Status Examination score >24.[28]

Exclusion Criteria

Symptomatic cardiovascular disease (coronary artery disease, congestive heart failure) at moderate exertion, poorly controlled hypertension (>160/96), history or physical findings of a focal neurologic deficit, Parkinson disease, or peripheral neuropathy of the legs, hip or knee joint replacement, hip fracture, and cancer (metastatic or under active treatment) were exclusion criteria. Subjects with poorly controlled blood pressure were encouraged to return after their blood pressure was below the exclusion level. Medication exclusions were neuroleptics, prednisolone >5 mg/day, and benzodiazepines. Subjects with arthritis or arthritic symptoms were not excluded, but subjects with significant knee or hip arthritis who required a cane for ambulation were excluded.

STUDY DESIGN

Subjects were randomized using a balanced block design (blocks of 24 subjects) to 1 of 4 groups: Control,[27] balance training,[28] resistive training,[27] and combined,[28] described in Table 1. Randomization was stratified by gender.

INTERVENTION

All training and education sessions were held at the Balance and Gait Enhancement Laboratory on the campus of the University of Connecticut Health Center.

Table 1. *Subject assignment to 4 training groups*

	Resistive Training		
Balance Training	Yes	No	
Yes	28	28	56
No	27	27	54
	55	55	110 total

Resistive Training

Exercise sessions were 45 minutes long, were held 3 times weekly, and consisted of 3 to 5 subjects and 1 or 2 exercise leaders. Resistive training employed a combination of resistive machines for knee extension and ankle dorsiflexion and sandbags for hip extension, hip abduction, and knee flexion. Body weight alone was used for ankle plantar flexors training. Static stretch of muscle groups was performed before resistive exercises to reduce the risk of muscle/tendon injury.

Sandbag/Body Weight Resistive Training

Exercises were designed, where possible, to provide the greatest resistance (vertical movement of the leg) at the range of motion used in functional activities. There was a 1 to 2-second rest between movements and a 2 to 3-minute rest between sets. Subjects exercised for 2 weeks with low resistance (0–2.4 kg) and concentrated on performing the exercise with good form and with minimal substitution of other muscle groups. 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 during the second set. At the end of training, subjects exercised with up to 14 kg of sandbag weights attached at the ankle.

1. Hip abduction was performed in a side-lying position with the thigh held in neutral hip rotation and the nonexercising leg flexed. The ROM of the exercise was from −10° to about 40° of hip abduction, with a 1-second lift, 1-second hold at full abduction, and 2 seconds to lower.
2. Hip Extension was performed in the prone position. Subject performed the movement slowly, with the goal of isolating hip extension and avoiding pelvic rotation and lumbar lordosis. Range of motion was from 0° to maximal hip extension.
3. Knee flexion was performed in the prone position, with a ROM from 0–90° of flexion.
4. Ankle plantar flexion was performed while standing. Subjects initially performed bilateral plantar flexions and progressed after Week 3 to unilateral plantar flexion. Two sets of 10 lifts were performed.

Resistive Machine Exercises

Knee extension was performed using a variable resistive machine (Titan Exercise Equipment, Carrollton TX). This machine uses weight plates attached to a cross bar. Unilateral resistive training consisted of 3 sets of exercise to failure. The extension was performed at about 45° s^{-1}, with a 1-second hold at full extension, and lowered at about 30° s^{-1}, with 1 to 2-second pause between lifts. On the third set, the back support was lowered to decrease the hip flexion angle from 85° to 55° to increase rectus femoris resting length and, theoretically, its contribution to knee extension moment. Resistance was set at 60% of 1 RM for the first week, 70% in the second week, and 75% after the third week. 1 RM tests were performed at 4, 8, and 12 weeks, and resistance was adjusted to 75% of 1 RM. Between 1 RM tests, resistance was increased when a subject completed 12 or more repetitions in all 3 sets.

Ankle dorsiflexion was performed in an upright sitting position on the trainer's table on a machine (Anklecisor, FEECO Inc., Green Bay WI). The movement was from 30° plantarflexion to maximal dorsiflexion. Two sets of exercise were performed at a resistance of 70% of 1 RM.

Balance Intervention

Balance training consisted of three 45-minute training sessions a week, with one-to-one instruction by the exercise leader, and included training on a computerized balance platform for half the session and floor-based exercises for the remainder. The platform-based training was performed on a force platform that could be tilted (axis of rotation at the ankle) and provided video feedback of center of pressure (COP) position (Balance Master Pro, Neurocom, Clackamas, OR). Subjects stood on the platform with a computer monitor at eye level, 0.6 m in front of the subject. Subjects were encouraged to move the COP position cursor as far as possible in specified directions, using a target "box" on the video screen. The target box positions were moved peripherally as the subjects' ability to move their COP improved. After several weeks, visual feedback was occasionally eliminated. Subjects responded to platform tilts of increasing amplitude in both anterior/posterior and frontal planes. Platform tilts were performed with eyes closed or without COP feedback.

Non-platform balance training included exercises with eyes open and closed. Training was in 4 areas: (1) single leg stance on carpet or foam; (2) slow forward and backward walking on carpet or foam, tandem gait, and walking on a 14-cm-wide board; (3) sitting-balance on large therapeutic balls; (4) perturbations of balance while sitting or standing on carpet or foam—subjects respond to pushes in all directions delivered by the exercise leader.

Combined Training

Subjects performed the full resistive and balance training at each session. The combined training session lasted 95 minutes and consisted of 45 minutes of balance training, a 5-minute rest, and 45 minutes of resistive training.

Control Group Intervention

Control subjects were encouraged to continue their usual activities, but were not permitted to begin an organized exercise program or an individualized training program during the intervention period. All subjects, including the control group subjects, participated in 5 educational sessions. These 90 minute sessions discussed fall prevention and stress management issues. There was no attempt to segregate sessions by treatment group.

OUTCOMES

Isokinetic Joint Moments

Peak joint moment achieved during the 60° s^{-1} isokinetic movements were the primary outcome variables. Testing was performed at least 48 hours before or after 1 RM tests, and was performed at baseline and at one to three weeks after the completion of the training. Testing was performed by physical therapists blinded to the group assignment of the subjects; the subject was tested by the same therapist at baseline and posttest. Isokinetic strength was measured on a Cybex 340 isokinetic dynamometer on the right limb at two angular velocities: 60° and 180° s^{-1} at the knee, and at 30° and 60° s^{-1} at the hip and ankle. Ankle plantar/dorsiflexion was performed in the supine position with the knee extended. Hip extension/flexion was performed in a supine position. Hip abduction/adduction was performed in the side-lying position with the pelvis stabilized.

Subjects practiced 4 warm-up movements and then performed 4 maximal movements for each joint movement, with 90 seconds rest between testing at each angular velocity. The order of joint testing was randomized, and the same order was used at post test. There was no correction for the moment (weight) of the limb.

The summary variable for leg strength was calculated as the sum of the peak joint moments obtained during 8 joint movements at 60° s^{-1}. This measure was felt to be the best summary estimates of muscle forces controlling the major movements of the hip, knee, and ankle, with the exception of hip rotation. Because of large differences between joint moments at the hip, knee, and ankle, the summary variable predominantly reflects hip strength. An alternate summary change measure was constructed to give an equal weighting of the change in all 8 joint movements. The average joint improvement was calculated as the percent [100 * (posttest − baseline)/baseline] change in each of the joint movements, which were summed and divided by 8. Three subjects (from resistive and combined training groups) who had baseline ankle momemts of 0 N m were not included in this analysis.

The within-subject correlation of moment between slow and fast angular velocities was high, (r = 0.83–0.95), and analysis of the results was not different if strength at 30° for the hip and ankle or at 180° s^{-1} for the knee was used. The Dynamometer was calibrated immediately before baseline and posttraining measurements for each cohort of subjects. Baseline and posttraining measurements were obtained over a 2-week period before and after training.

Performance Measures

Gait velocity was measured by photocells and an electronic timer on an 8-m carpeted course. For usual pace, subjects were instructed to walk as they usually walked. For the fast pace, subjects was instructed to walk as fast as they could walk safely. The average of 3 trials at each pace is reported. Walking cadence was determined from the time needed to take 10 steps (steps 2–12), measured by stopwatch, during the third trial at each pace. Average step length was calculated by dividing velocity (m s^{-1}) by the time needed to take a step (s/step). Gait velocity was highly reproducible, determined by the within-session coefficient of variance (0.05 for usual pace and 0.04 for fast pace).

Chair rise time was measured using a stop watch. The subject was instructed to rise without the use of hands or arms on hearing the word "Go." Timing was from the word "Go" until the subject was fully upright. One subject was unable to rise without the use of hands and is not included in the analysis. The average time of 3 trials is reported.

Repeated measures ANOVA found a small but significant within-session improvement from the first to the third trial, 1.28 ± 0.77 s to 1.14 ± 0.49 ($F(2,216)$, $P = 0.001$). Within testing session reproducibility, determined by the coefficient of variance, was 0.14.

Injury Prevention/Response

Subjects were asked frequently about musculoskeletal or neurologic complaints. Symptoms were evaluated by a geriatrician, and modifications were made to the training program. Modifications usually involved a 1-week rest from the resistive exercise(s), static stretch exercises only for 1 week, and slow reintroduction of resistance with increased concentration on correct form. All subjects were able to continue in the resistive training program.

Compliance

Subjects attended 82% of resistive sessions, and in sessions attended, subjects completed 93% of assigned sets. Subjects were considered drop-outs only if they refused to return for repeat testing. All subjects who stopped attending exercise or discussion sessions were contacted and were encouraged to return for posttest results. Posttest results were obtained in 98 subjects for isokinetic measures and on 96 subjects for 1 RM measures, a retention rate of 89%. Complete isokinetic data were obtained from 92 subjects at posttest; 6 subjects did not perform 1 or more joint movements.

Statistical Analysis

Statistical analysis was performed on SPSS 5.0 software. Analysis was performed for a 2 x 2 factorial intervention, using an intention-to-treat analysis. Exploratory data analyses determined the variability and distribution of outcome variables. Paired t tests were first performed on the summary measures for each group and for 1 RM tests.

Pearson correlation coefficients tested for multicolinearity between joint moments at 2 angular velocities. ANOVA tested for comparability of muscle strength measures at baseline for each joint movement, and each summary joint measure by group, and by training assignment (2 factors). Homogeneity of variance assessed by Cochran's (univariate), and Box's M test (multivariate) determined that the variance of outcome measures did not differ between training assignment for the primary outcome variables.

Repeated measures MANOVA tested for the effect of training assignment on primary outcome variables. The within subject effect of resistive training (2 levels), balance training (2 levels), and the interaction of balance and resistive training (additive or synergy) were tested. MANOVA provided estimates of the training (not group) effect. The coefficients with 95% confidence intervals are reported as the effect (in N m) of training assignment (resistive, balance) and interaction effect (resistive * balance) on joint moments. Descriptive statistics only were performed for the percent change in joint moments (mean, 95% Confidence interval for the mean).

The effect of gender on baseline strength was tested with ANOVA, and the effect of gender on response to training was tested using the model: gender x balance x resistive, with interactions. Statistical significance was set at $P < 0.05$.

RESULTS

Baseline

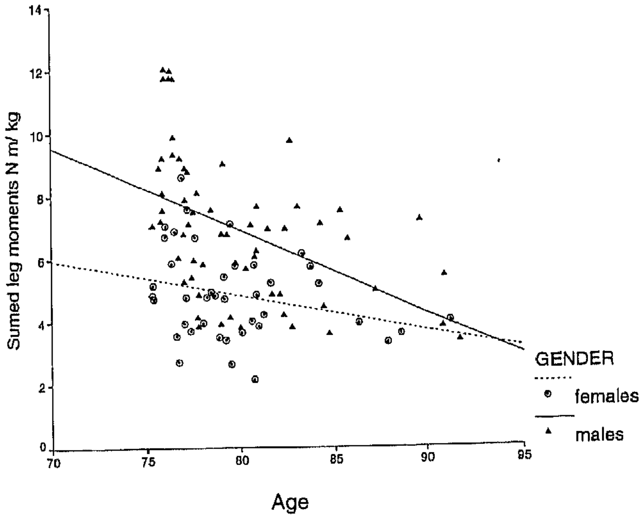
The recruitment and screening process resulted in a well educated and relatively healthy sample. The majority of subjects rated their health as excellent or good (Table 2) and had attended, on average, 3 years of college. Only 18 subjects had difficulty with any instrumental activities of daily living.[27] The Sickness Impact Profile subscale scores[29] reflected low perceived difficulty with ambulation and mobility activities. Demographic and functional status variables for the 4 groups were comparable (ANOVA $P > 0.3$ for all variables). The resistive trained groups tended to be weaker at baseline (ANOVA, F 2.2, $P = 0.14$) for the summary joint moment measure. Individual joint moment or work measures did not differ by group or training randomization.

Leg strength corrected for body mass declined with increasing age in the sample (Figure 1), and the slope of the linear regression was $-$ 0.22 N m kg^{-1}/year for all subjects. When analyzed by gender, however, the loss of strength was significant only for men (the slope of strength loss vs age was

Table 2. *Baseline characteristics by intervention group. (mean ± SD)*

Intervention Group	Control	Balance	Resistive	Combined
n	27 (00)	28 (00)	28 (00)	27 (00)
Age (years)	80.6 ± 4.5	78.9 ± 2.8	80.3 ± 4.0	79.5 ± 4.1
Male N (%)	16 (59)	16 (57)	17 (61)	15 (56)
Body mass (kg)	73 ± 13	69 ± 14	70 ± 10	71 ± 17
Height (cm)	164 ± 10	164 ± 10	164 ± 10	166 ± 11
Education (years)	15.0 ± 3.5	15.1 ± 2.6	14.7 ± 3.1	15.4 ± 3.2
Health Rating N (%)				
Excellent/Good	11 (42)	12 (44)	11 (44)	14 (56)
Good/Fair	15 (58)	15 (56)	14 (56)	11 (44)
Mini-Mental Status score (0–30)	28.8 ± 1.7	28.6 ± 1.0	28.1 ± 1.6	28.3 ± 1.5
IADL score (0–24)	23.5 ± 1.0	23.7 ± 0.7	23.7 ± 0.8	23.9 ± 0.4
SIP Ambulation (0–80.4)	3.8 ± 5.4	4.6 ± 6.9	5.9 ± 8.8	9.7 ± 11.8
SIP Mobility (0–71.9)	2.3 ± 5.9	1.3 ± 2.9	1.9 ± 5.3	2.9 ± 5.0
Fell in past year *n* (%)	7 (27)	9 (33)	9 (35)	7 (28)
Regular exercise ≥1/week *n* (%)	18 (69)	18 (69)	21 (81)	15 (60)

Figure 1. *Relationship between age, gender and summary leg strength, corrected for body mass. Solid triangles = males, circles = females, with separate linear regression lines by gender. The regression equation for men is Strength = 28 − 0.26 Age (years).* $R^2 = 0.23$, $P = 0.001$. *For females, the slope of the regression was not significantly different from 0. Strength = 12.8 − 0.11 * Age (years),* $R^2 = 0.08$, $P = 0.06$.



− 0.28 N m kg^{-1} per year, $P = 0.001$). The summary strength measure was 30% lower in women than in men (4.8 ± 1.4 N m kg^{-1} in women, 6.2 ± 2.3 N m kg^{-1} in men, F = 26.1 (1, 99), $P < 0.001$), after correcting for body mass. Women were significantly weaker than men in all isokinetic measures except ankle plantar flexion. Ankle plantar flexion strength in women tended to be lower (13%) than in men (0.57 ± 021 N m kg^{-1} in women, 0.66 ± 0.28 N m kg^{-1} in men, $P = 0.08$).

Performance Measures

Mean gait velocity at usual pace was 1.11 ± 0.20 m s^{-1}, and at fast pace was 1.59 ± 0.29 m s^{-1}. Step length at usual pace was 61.7 ± 10.0 cm, and at fast pace was 72.0 ± 11.0 cm. The mean time to rise from sitting to standing was 1.23 ± 0.62 s; the distribution of chair rise time had moderate variability and was skewed toward high values—several subjects took more than 3 seconds to rise.

Effects of Training

Knee extension 1 RM on the machine used for resistance training increased 62% after 13 weeks of training compared with baseline (95% CI 42–84%, $P < 0.001$, from 45 ± 21 N m to 71 ± 26 N m) in the resistive trained group and increased 45% (30–60%, $P < 0.001$, 48 ± 21 N m to 69 ± 26 N m) in the combined group. Similar improvements in ankle dorsiflexion 1 RM occurred. The resistive trained group 1 RM increased 73% (46–98%, $P < 0.001$), and the combined group increased 58% (39–77%, $P < 0.001$)

The resistive trained group increased summed joint moments from 8 joint movements 49 ± 45 N m compared with baseline, (13% increase, $P < 0.001$), and the combined training group increased joint moments 81 ± 60 N m compared to baseline. (21% increase, $P < 0.001$) (Table 3). Figure 2a is a boxplot of the change in strength results for each group, and Table 3 lists the mean ± 1 SD results for each training group. The balance training and control groups did not increase summed joint moments (−12 ± 49 N m and −13 ± 82 N m, respectively, $P > 0.3$).

MANOVA tested for the independent effects of balance and resistance training. MANOVA determined that resistive training had an independent effect on improvement in summed joint moments, after correcting for differences in strength at baseline (F = 21.1, $P < 0.001$). Balance training did not improve the summary measure, (F = 0.3, $P = 0.60$) and there was no interaction between resistive and balance training (F = 1.1, $P = 0.29$). The estimated effect of resistive training, correcting for balance training and interaction effects, was to increase joint moment 41 N m (95% CI 27–56). Figure 2a demonstrates that the median improvement in joint moments was greater in the combined training group, but as noted above, MANOVA did not suggest an additive effect of combined resistive and balance training.

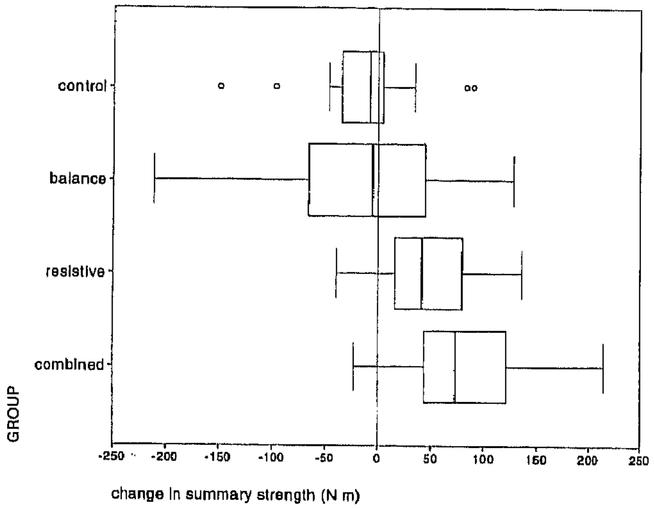
Figure 2b and Table 4 demonstrate the results of an alternate approach to summary strength analysis, using summary variables which are the average percent improve-

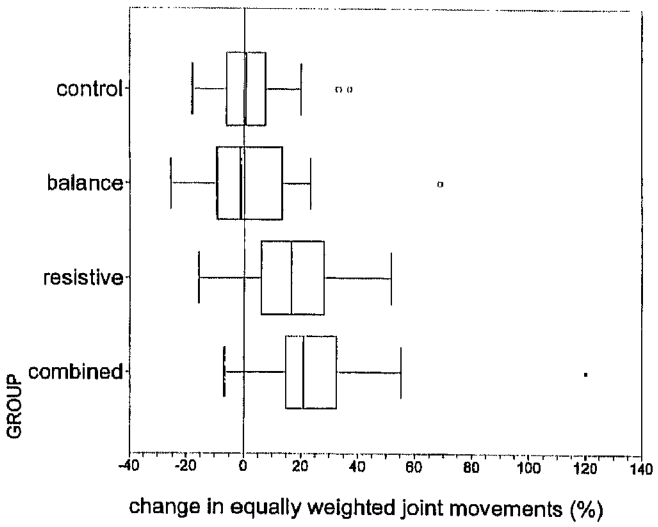
Table 3. *Baseline strength values and effect of training*

Joint Movement Mean ± SD Joint Moment (N m)	Control		Balance		Resistive		Combined		Resistive Training Effect (N m) MANOVA (95% CI)
	Baseline	Change	Baseline	Change	Baseline	Change	Baseline	Change	
Hip extension	88 ± 49	−4 ± 26	105 ± 47	−14 ± 21*	84 ± 34	13 ± 24*	87 ± 42	16 ± 31*	11 (6, 16)*
Hip flexion	44 ± 26	2 ± 13	50 ± 27	−1 ± 20	39 ± 17	7 ± 9*	43 ± 24	5 ± 16	3 (0, 6)
Hip abduction	43 ± 22	0 ± 11	55 ± 22	−2 ± 22	41 ± 20	3 ± 15	41 ± 21	7 ± 22	3 (−1, 7)
Hip adduction	83 ± 57	−7 ± 20	96 ± 46	−6 ± 36	75 ± 48	7 ± 18	78 ± 53	28 ± 26*	11 (6, 16)*
Knee extension	89 ± 37	0 ± 11	99 ± 39	3 ± 15	73 ± 32	13 ± 18*	79 ± 28	17 ± 14*	5 (3, 7)*
Knee flexion	55 ± 22	3 ± 11	66 ± 27	4 ± 12	50 ± 24	7 ± 12*	51 ± 21	12 ± 15*	3 (0.5, 5)*
Ankle plantar-flexion	35 ± 18	−1 ± 9	35 ± 14	2 ± 10	31 ± 16	4 ± 8*	31 ± 12	8 ± 10*	2 (0.5, 4)*
Ankle dorsi-flexion	11 ± 5	1 ± 3	12 ± 8	1 ± 5	8 ± 4	2 ± 3*	8 ± 7	2 ± 6	0 (−0.5–1)
Summary moment (N · m)	451 ± 221	−12 ± 49	530 ± 203	−13 ± 82	409 ± 77	49 ± 45*	408 ± 153*	81 ± 60*	41 (27–56)*

* $P \leq 0.005$.

Figure 2. *Box plots of change in summary joint measures by group assignment. Box outline includes the 25–75 percentile response. The middle line in the box is the median value. The bars represent the highest and lowest (non-outlier) values. Circles represent outliers >1.5 box lengths above or below the 25–75 percentiles, and extreme values (*) are >3 box lengths above or below the 25–75 percentile. 2a. Absolute difference in summed joint moments (follow-up − baseline). 2b. Percent change in leg strength, calculated by the average change in 8 joint movements.*





ment in joint moment from baseline, with each joint movement given equal weight. These variables were not normally distributed because of extreme positive results in subjects in the resistive and combined groups who had very low strength at baseline. For this reason, the median rather than the mean improvement is reported for each group. The median percent increase in the 4 hip moments was 15% for the resistive training group and 30% for the combined training group. The median percent improvement in all 8 joint movements (18% in the resistive group and 21% in the combined group) was similar to the mean improvement in summed joint moments, the primary outcome variable.

Individual peak joint moments were secondary outcomes (Table 3, Figure 3). Resistive training increased peak moments and work in 5 movements, with nonsignificant improvements in hip abduction, hip flexion, and ankle dorsiflexion. For example, in knee extension, joint moment increased 18% over baseline, from 73 ± 32 N m to 86 ± 34 N m ($P < 0.001$), in the resistive-trained group, and increased 22% (from 79 ± 28 to 96 ± 30 N m) in the combined group. Table 3 lists the peak moment results for all joints. The balance group or control groups did not increase joint moment in any joint movement. There were no significant interactions between balance and resistive training for any joint movement. The combined group had a striking increase in hip adduction 28 ± 26 N m ($P > 0.05$), although hip adduction was not directly trained.

Performance Measures

Gait velocity increased at posttest in the entire sample from 1.11 ± 0.20 m s^{-1} to 1.14 ± 0.21 m s^{-1}. MANOVA determined that there was a repeated measures effect (F = 7.1, $P = 0.009$); the improvement occurred in the resistive and control groups only, and balance-trained groups did not walk faster (F = 6.8, $P = 0.01$). There was no effect of resistive training, or interaction between training. Balance training was associated with slower gait velocity at posttest. The estimate of the effect of balance training was -0.03 m s^{-1} ($P = 0.01$, 95% CI 0.01, 0.04 m s^{-1}). Fast pace gait did not improve following training (1.59 ± 0.29 to 1.60 ± 0.29 m s^{-1} for all subjects) in any group.

Chair rise time was not faster at follow-up (1.23 ± 0.62 s at baseline to 1.16 ± 0.52 s for all subjects). There were no differences between groups, and there was no suggestion of any trend for either balance or resistive training effects (F < 0.5, $P > 0.6$ for both balance and resistive). However, there was a weak correlation between baseline and follow-up measures ($r = 0.31$).

Side-Effects of Training

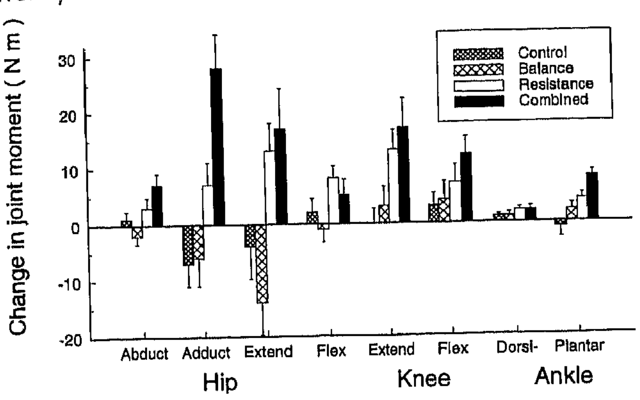
Musculoskeletal complaints developed in 10 of 55 subjects who were in the resistive or combined training groups; these were possibly or probably related to resistive training.

Table 4. *Percent change in joint moments following training movements equally weighted*

Joint Percent Change from Baseline Mean, (95% CI)	Control	Balance	Resistive	Combined
Ankle	−1 (−9, 7)	15 (−13, 43)	15 (−12, 43)	22 (−1, 45)
Knee	5 (−2, 12)	6 (−1, 12)	19 (8, 31)	24 (13, 35)
Hip	4 (−5, 12)	−4 (14, 6)	17 (7, 27)	25 (13, 37)
All 8 joint moments	3 (−3, 8)	3 (−6, 13)	19 (10, 28)	26 (15, 39)

For each joint, the % change represents the average improvement in the 2 (4 for hip) motions measured at the joint. This gives equal weight to each movement.

Figure 3. *Change in individual joint measures, by group assignment, in N m.* r = *resistive training. Error bars = 1 standard error of the mean.*



Complaints were of hamstrings cramping,[3] tenderness at the origin of the hamstrings,[1] trochanteric bursitis,[1] cramping or tenderness at the origin of the rectus femoris,[2] lower back complaints,[2] and knee pain.[1] With modifications in resistive program described in the methods section, all subjects were able to continue with resistive training. In contrast, only 1 subject developed a complaint that was possibly related to balance training.

DISCUSSION

This study demonstrated that resistive training using sandbags and simple resistive machines improved overall isokinetic leg strength in healthy community-dwelling subjects over 75 years of age. Resistive training increased strength in 5 of 8 movements tested, and in 4 of 6 movements trained. Two trained movements (ankle dorsiflexion and hip abduction) did not improve. The finding of significant strength gains in the summary leg strength measures is important because strength measures, excepting knee extension and hip abduction, were obtained in positions and movements different than were trained and in movements that were not directly trained (hip adduction and hip flexion). This is the first randomized control intervention trial to demonstrate a significant increase in overall lower extremity strength using outcome measures that were different from performance on machines used in training.

The findings of the present report are most comparable to a resistive training program by Frontera,[20] in older men aged 60–72, which used a similar isokinetic protocol to measure muscle strength after training on resistive machines. The percentage improvement in knee extension isokinetic moment in the present study (20% for both resistive trained groups) is greater than the Frontera study (10%), but the absolute strength improvements (15 N m in the present study vs 12.5 N m in Frontera) are similar. Training in the Frontera study involved heavier resistance exercise (unilateral lifts, with 3 sets at a resistance of 80% of 1 RM) and was well tolerated by the subjects.

The present study extends the findings of Charette,[23] who trained multiple leg muscle groups in older women (mean age 69 years) and improved maximum lifts (1 RM) from 28 to 115% on the training machines, without musculo-skeletal injuries. The present study demonstrates the efficacy of training multiple muscle groups in a population 10 years older.

Most resistive intervention studies have reported improvements on the training machine (weight lifted) as the primary outcome measure, and have reported much greater percentage improvements than the few studies that used a different machine to assess improvement attributable to training.[19, 20, 23] Differences between gains on training machines and isokinetic measures reflect the known specificity of resistive training: gains are greatest at the speed, range of motion, and type of contraction (concentric, isokinetic, eccentric) used in training.[30, 31] The difference between ankle dorsiflexion 1 RM and isokinetic moment or work in the present study is a striking example of the specificity of training effect and reflects the problems inherent in using training machines for outcome measures. In the present study, ankle dorsiflexion 1 RM, measured on the training machines, increased (65%) in the resistive trained groups, but isokinetic measures increases were much smaller and nonsignificant (25%). We do not infer that isokinetic measures are superior to 1 RM measures. In intervention trials, strength outcome measures have more clinical meaning if the outcome measures differ from the training activities.

The lack of improvement in ankle dorsiflexion may be due to inappropriate exercise design, low exercise intensity, and variability between repeated measures. The subjects had low dorsiflexion strength at baseline (10 ± 6 N m), and the weak subjects had peak moments comparable to the reported precision of the measurement (1.3 N m). As ankle dorsiflexors are usually active in upright positions with the knee near full extension, training dorsiflexor strength in a knee extended position is probably more clinically useful. The present results suggest that either training with the knee extended, or using higher resistance (80% of 1 RM), will be necessary to increase isokinetic ankle dorsiflexor strength.

Hip abductor strength did not improve, despite substantial increases in exercise resistance, and close supervision to prevent muscle group substitution was discouraging. In contrast, a companion FICSIT intervention, which used trained hip abduction and adduction on resistive machines, improved isokinetic hip abduction moment 25% after 6 months of training.[32] The differences in results suggests that resistive training on machines for 6 months is required to improve hip abduction strength. It is possible that sandbag training at a higher resistance will also be effective.

The improvement in hip adduction in the resistive training groups was unexpected. The hip adductors may have contracted isometrically to stabilize the femur during knee extension and flexion or during hip extensions, but there was no specific training for this muscle group. The increased strength in this muscle group may be due to improved muscle activation, a generalized effect of resistive training. This possibility has been reviewed by Sale[33] and was first suggested by Moritani.[34]

The combined training group's absolute improvement in strength was greater than the improvement in the resistive training (74 N m vs 57 N m). The lack of an interaction effect is probably attributable to the high variability in the response to training, demonstrated in Figures 2a and 2b. Some of the variability in repeat measures may be caused by seasonal effects[26] on strength, in addition to the inherent variability of the isokinetic measures. Wide variability in response to resistive training was also found in another FICSIT intervention trial.[32]

It is difficult to estimate the clinical impact of the strength gains in this sample of highly functional subjects. Analysis of cross-sectional data can give some perspective to the improvements in the present intervention. The cross-sectional analysis of the present study found that age was associated with a loss of 0.22 N m/kg in summary leg strength per year (all subjects). The average improvement in the 2 resistive trained groups was 1.05 N m kg^{-1}, which can be interpreted as similar to regaining about 5 years of loss in muscle strength associated with age.

The subjects in this study were substantially weaker than subjects in a cross-sectional study by Frontera of older adults who were 10 years younger.[28] Peak isokinetic knee joint moments at 60° s^{-1} in the resistive trained subjects in the present study (mean age 79 years) were 26% lower in men, and 33% lower in women compared with subjects aged 65–78,(mean age 69 ± 3 years). Both studies used the same protocol to measure knee strength. Following training, the resistive-trained men in the present study improved knee strength from 2.08 to 2.46 N m kg^{-1}, but at posttest were still 12% weaker than men in the Frontera study, who were 10 years younger (2.8 N m kg). Women achieved similar gains—strength improved from 1.48 to 1.79 N m kg^{-1}, but at posttest remained 18% weaker than women who were 10 years younger (2.18 N m kg).

Limitations

The resistive training program used in this study was designed to be readily exportable from the exercise laboratory to senior centers and community facilities. For this reason, we used sandbags and inexpensive resistive machines. Sandbag exercises are attractive because they can be incorporated into group and home-based exercise programs, but they also have the potential for muscle substitution, excessive spine or pelvic motion, and risk of musculotendinous injury caused by lack of trunk stabilization. The 20% incidence of musculoskeletal complaints that occurred during resistive training were concentrated at the hip/pelvis. All subjects were managed conservatively, and all completed the resistive training program with minor modifications in their training. However, the 20% incidence of musculoskeletal complaints was higher than reported by other interventions using resistive machines[19, 20, 23] and suggests that careful attention to exercise form and resistance are very important when using sandbag resistance. It is important to note that the present protocol set sandbag resistance at a moderate intensity, based on the subjects ability to complete 12 or more repetitions per set with good form. This is a lower intensity than was used in earlier resistive machine studies.

There is evidence that more intense resistive training with sandbags, or using resistive machines to train individual muscle groups, may be more effective than the present program in increasing overall leg strength. It is also possible that resistive machines for knee flexion, hip extension, and hip abduction may result in a lower incidence of musculoskeletal complaints than the experience in this trial. Also, this intervention did not include isolated training of the hip flexors and hip adductors, which may be important components of lower extremity function.

Training did not achieve clinically meaningful improvements in the physical performance measures (Table 5). The small increase in usual gait velocity in the control and resistive training groups (0.03 m s^{-1}) was not associated

Table 5. *Performance measures*

Measure	Control		Balance		Resistive		Combined		MANOVA (95% CI)
	Baseline	Post	Baseline	Post	Baseline	Post	Baseline	Post	
Gait Velocity-Usual (m s^{-1})	1.08 ± .19	1.14 ± .17	1.15 ± .18	1.18 ± .22	1.09 ± .20	1.17 ± .22	1.11 ± .21	1.08 ± .21	Repeat* (.03, 0.01, 0.04) Balance* −0.03 (−0.01, −0.04)
Gait Velocity-Fast (m s^{-1})	1.58 ± .28	1.61 ± .29	1.65 ± .26	1.65 ± .32	1.53 ± .80	1.55 ± .31	1.59 ± .29	1.59 ± .25	
Chair Rise time (s)	1.25 ± 0.70	1.13 ± 0.34	1.01 ± 0.35	1.22 ± 0.84	1.29 ± 0.73	1.18 ± 0.41	1.30 ± 0.64	1.11 ± 0.40	

with an increase in maximal gait velocity. The lack of improvement in fast pace gait, combined with an increase in usual gait velocity in the control and resistive trained groups, means that subjects in the control and resistive groups walked at a higher proportion of their maximal voluntary gait velocity at posttraining testing, and balance trained groups did not. Balance training did not change usual gait velocity. Balance training focused on the quality, not the speed of movement, and this may explain why the balance-trained groups walked slower at posttest. The lack of improvement in gait velocity with training contrasts with an earlier study in life-care community residents who performed balance and resistive training.[35] These subjects had a lower baseline gait velocity (1.04 m/s) than the subjects in the present study (1.11 m s^{-1}) and were not as functionally independent, although the average ages of the subjects were similar. Thus, we found no evidence that resistance training, which is effective in improving overall leg strength, improved gait function.

The lack of improvement in chair rise time may reflect low reproducibility of this measure and/or lack of efficacy of the interventions. The modest relationship (Pearson r = 0.31) between baseline and posttest rise time seriously reduced the power of the study to detect small differences in rise time. Also, the subjects in the present study were highly functional and had fast chair rise times at baseline. Chair rise time was about 1 second in this healthy group, although a few subjects required more than 3 seconds to rise. While the measure was reproducible within testing sessions, the short duration of the task makes the measure highly dependent on the reaction time of the tester. For healthy older subjects, the time to rise and sit several times may be preferable to a single chair rise time as a performance outcome and has shown good reproducibility in a large prospective study.[36]

The role of endurance training was not addressed in this study. Three recent studies have combined endurance and moderate resistance training with strength and endurance improvements.[26, 32, 37] Another recent study added a resistive training component to endurance training for women, without injury and with improvements in body composition.[24] The University of Washington FICSIT trial found that combined endurance and resistive training achieved smaller increases in isokinetic moments compared with the group that performed resistive training only.[32] However, older persons may achieve greater functional gains or maintenance of function by combined resistive and endurance training, if injury rates are low.

CONCLUSION

In this group of independent older subjects, multiple resistive exercises were tolerated by most subjects and improved overall lower extremity strength as well, but they did not improve performance measures, which are proxies for function. The program used here has the potential to be a component of a primary prevention strategy to reduce the contribution of muscle weakness to functional loss. The program also has potential, as part of a secondary prevention strategy, to improve muscle strength in persons with leg weakness and mild functional impairments. Long-term interventions using this type of training in well defined subject samples at risk for disability will determine the utility of resistive exercises as primary and secondary preventive strategies to maintain independent function.

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