

Effect of Intense Strength Training on Standing Balance, Walking Speed, and Sit-to-Stand Performance in Older Adults

Jeffrey Schlicht,¹ David N. Camaione,¹ and Steven V. Owen²

¹Center for Health Fitness, Department of Kinesiology, University of Connecticut, Storrs.

²University of Texas Medical Branch, Galveston.

Background. Muscle size and strength decrease with aging, and the resultant muscle weakness has been implicated in increased risk of falls in older adults. These falls have large economic and functional costs.

Methods. The purpose of this randomized, controlled study was to determine if an 8-week, 3-day per week intense ($77.8 \pm 3.4\%$ of 1-repetition maximum [1RM]) strength training program could improve functional ability related to the risk of falling in subjects aged 61–87 years (mean 72, *SD* 6.3). Twelve strength-training-naïve subjects performed two sets of 10 repetitions for six lower body exercises while 12 subjects served as nonintervention controls. Subjects were tested pre-, mid-, and postintervention for strength gain and on three tests of functional ability.

Results. Postintervention strength was significantly better ($p < .017$) in all training subjects across all exercises, and no injuries were reported as a result of either training or 1RM testing. After controlling for preintervention differences, repeated measure analysis of covariance (ANCOVA) found a significant difference between experimental and nonintervention control subjects for postintervention maximal walking speed [$F(1,19) = 5.03, p < .05$]. There were no significant between-group differences for 1-leg blind balance time or 5-repetition sit-to-stand performance [$F(1,19) = .082, F(1,19) = .068$, respectively, $p > .05$].

Conclusions. These findings suggest that strength training alone does not appear to enhance standing balance or sit-to-stand performance in active, community-dwelling older adults but that it may improve maximal walking speed. The relationship between strength gain and risk of falls remains unclear. The data do reinforce the notion that intense strength training is a safe and effective way to increase muscle strength in this population.

BIOLICAL markers indicate that muscle mass decreases by 50% between the ages of 20 and 90 years (1). This results in strength loss, which has been associated with an increased risk of falling and osteoporosis. These increased risks are related to the number of hip fractures occurring in older adults (2), which were estimated to cost \$7 billion annually in 1984 (3). The cost seems certain to increase as the mean population age continues to rise. More importantly, 80% of people who suffer hip fractures associated with osteoporosis never regain their prefracture functional status (4).

One way to help contain these financial and functional costs may be through the promotion of strength training exercise in older adults. Many studies involving elderly populations have shown that resistance training can result in increases in lower body muscle mass and strength, and it is reasonable to suppose that stronger legs provide a more stable base of support. Leg weakness has been identified as an important risk factor for falls (5), and functional tasks, such as walking speed (6), balance (7), and sit-to-stand performance (8) have also been related to fall risk.

However, strength training studies involving elderly populations have typically looked at strength or bone density change as primary outcome measures; the question of how these changes relate to the risk of falling or to fall outcomes is unresolved.

Those exercise studies that have attempted to address the impact of strength gain on the incidence of falls, or functional tests that are correlated to fall risk, have usually included multidimensional exercise interventions that weave together strength, flexibility, and aerobic training. They have not often addressed single exercise modalities.

The purpose of this study was to examine the effect of intense, lower-body strength training, apart from other modes of exercise training, on three functional tests related to the risk of falling. We hypothesized that intense strength training would improve balance, maximal walking speed, and sit-to-stand performance in moderately active older adults.

METHODS

Subjects and Procedures

The volunteer sample comprised moderately active (i.e., home and yard work, recreational walking), community-dwelling men and women from the area surrounding the University of Connecticut, Storrs. Subjects were recruited after lectures at two local Senior Centers and through public service announcements published in two regional newspapers. People 60 years of age and older were eligible to participate. Exclusion criteria included dependent living status, current involvement in a strength-training program, and

physiological disorders that (i) precluded strenuous exercise or (ii) affected vestibular function. All 24 subjects were apparently healthy, had physician consent to participate, and completed both a medical screening questionnaire and a university-sanctioned informed consent form prior to training. This study was approved by the University's Internal Review Board.

The subject pool was composed of 14 women and 10 men. Their ages ranged from 61 to 87 (mean 72, *SD* 6.3). Subjects were randomly assigned to either the experimental or nonintervention control conditions, with equal numbers ($n = 12$) placed in each. One subject from each group dropped out during the study, leaving 11 subjects in each group.

Strength Training Protocol

Training subjects exercised 3 days a week over 8 consecutive weeks. They performed two sets of 10 repetitions of six lower-body lifts. A summary of the exercises performed, muscle groups trained, and equipment used appears in Table 1.

The first 2 weeks of training were an acclimation period. After the subjects were introduced to the equipment and shown how to perform each exercise correctly, they spent the first six training sessions lifting self-selected weights. Subjects were instructed to choose a weight that was comfortable for them and were encouraged to increase the weight when they felt that the tenth repetition of either set was becoming easy.

There were several reasons to include an initial acclimation period. Much of the initial change in strength that occurs with training is due to neuromuscular improvements that result in increased muscle fiber recruitment (9). Also, most injuries that occur during weight training studies happen during the first 2 weeks (10). Finally, the introduction of new skills involves a predictable learning curve. The acclimation period allowed for neuromuscular improvements and learning to occur. It also allotted time for the experi-

menter to provide feedback and corrections about posture and exercise execution while the training stimuli were less intense. This helped to ensure that a true 1-repetition maximum (1RM) was initially measured and reduced the risk of injury.

For the remaining 6 weeks, training stimuli were set at 75% of each subject's 1RM score for each exercise. Because strength was expected to increase with training, 1RM testing was conducted every 2 weeks. Training stimuli were recalibrated to 75% of each new 1RM score.

To promote a robust training effect, subjects were encouraged to increase training weights during each 2-week block whenever they felt they could do more than 75% of their latest 1RM score. In fact, by the end of each 2-week training block, the average training weight was $77.8 \pm 3.4\%$ of the previously measured 1RM score.

Organized warm-up or stretching periods were purposefully avoided, because the intent of this study was to examine the unique contribution of strength training to the functional tests described below.

Outcome Measures

Muscle Strength.—Muscle strength was measured using the 1RM method for each exercise, which has been shown to be safe and effective in older adults (10) and has been described elsewhere (11). 1RM testing occurred on a regularly scheduled training day and constituted the workout for that day. To record a true maximum lift before muscle fatigue interfered with ability, the goal was to capture a 1RM score within 3 to 5 attempts (i.e., no more than five successful lifts before failure). This was accomplished 98% of the time (253/255 1RM tests). A total of four 1RM tests were conducted (at Week 2, Week 4, Week 6, and Week 8).

Maximal Walking Speed.—Maximal walking speed (MWS) was measured by timing subjects as they walked across a 25-foot stretch of firm, uncarpeted, unwaxed wood floor. The total length of the marked walkway course was 45 feet, allowing for 10-foot acceleration and deceleration zones. The width of the walkway was set at 3 feet to encourage subjects to maintain a straight course. Tape strips across the width of the box marked the end of the acceleration and the beginning of the deceleration zones.

Subjects performed two timed trials. Once testing was complete, the best time was converted to a speed measurement and recorded in metric units (m/s). Times were calculated using a digital stopwatch (Chronus Pro Survivor; AST/CPPI, San Jose, CA). Maximal walking speed measurements were taken pre-, mid-, and postintervention.

5-Repetition Sit-to-Stand.—Sit-to-stand (STS) was measured by timing subjects as they stood up and sat down as quickly as possible on a firm, padded, armless chair on which the seat was 18.5 inches from the ground. The same chair was used for all subjects during all test periods. The chair back was supported against a wall, and subjects were instructed to fold their arms across their chests before beginning the test. This protocol is similar to those described in the literature as being reliable and correlated with fall and balance (12).

Table 1. Strength Training Exercise Protocol

Exercise	Primary Muscle Groups Trained	Equipment Used
Leg extension	Quadriceps	Universal 8-Station, Cedar Rapids, IA
Inner thigh press	Hip Adductors Pectineus Gracilis	Paramount Fitness Equipment Corp., Los Angeles, CA
Outer thigh press	Sartorius Tensor Fasciae Latae Gluteus Medius Gluteus Minimus	Paramount Fitness Equipment Corp., Los Angeles, CA
Glute press	Gluteus Maximus Hamstrings	Cybox International, Owatonna, MN
Leg press	Gluteus Maximus Quadriceps Hamstrings	Universal 8-Station, Cedar Rapids, IA
Ankle press	Gastrocnemius, Soleus Tibialis Posterior Plantaris Peroneals	Universal 8-Station, Cedar Rapids, IA

Subjects performed two timed trials. The beginning of the timed test was prefaced with, "Ready, Set, Go" by the tester. The stopwatch was started after the word "Go," and the tester counted aloud each of the five completed STS cycles. The stopwatch was stopped when the subject returned to the seated position for the fifth time. Times were calculated using a digital stopwatch (Chronus Pro Survivor). Sit-to-stand measurements were taken pre-, mid-, and postintervention.

One-Legged Blind Balance.—Balance was measured by recording how long the subjects could remain standing on one leg with their eyes closed. Subjects were instructed to stand shod in an 18" by 20" square, marked by tape on a firm, uncarpeted, unwaxed, level wood floor. After deciding which leg to use as the support leg, subjects were instructed to lift the opposite foot from the floor, making sure not to brace the lifted leg against the support leg. Once the leg was lifted, subjects were told to close their eyes. Once their eyes were closed, test timing began. The test ended when (i) the subjects opened their eyes, (ii) the lifted leg touched the support leg, (iii) the support foot touched any part of the square outline, (iv) the lifted leg touched the floor, or (v) after 30 seconds of successful balance.

Subjects were allowed five timed trials. Times were calculated using a digital stopwatch (Chronus Pro Survivor). Balance measurements were taken pre-, mid-, and postintervention.

Statistical Analyses

All data were analyzed using the SPSS computer package (SPSS V. 9.0; Chicago, IL).

Strength.—Paired samples *t* tests were used to compare 1RM data. Each set of data from the six exercises was tested three times (Week 2 vs Week 4, Week 4 vs Week 6, Week 6 vs Week 8), so a Bonferroni adjustment was used to reset the nominal alpha level from .05 to .017.

Functional Tasks.—Significant differences between experimental and control subjects on each of the three performance tests were examined using a 2 × 2 (Group × Time) repeated measures ANCOVA design, where the baseline (preintervention) score served as the covariate. The alpha level was set at .05.

Planned comparisons were completed post-hoc via paired sample *t* tests to examine within-group relationships. Each set of data for the three functional tasks were tested three times (pre-mid, pre-post, mid-post), so a Bonferroni adjustment was used to reset the ANCOVA nominal alpha level from .05 to .017.

RESULTS

Attendance and Attrition

At the beginning of the 8-week study, one experimental subject withdrew. This male subject dropped out after the introductory training session, and subsequent attempts to contact him for an explanation were unsuccessful. One male subject in the control group was dropped from the analyses because he was unable to attend the final data collection.

The remaining 11 experimental subjects attended 99% of the total possible workouts (262/264 sessions), and data were collected from all 11 remaining control subjects at each of the three data collection points.

Strength Comparisons

Table 2 presents mean strength scores for each of the six exercises at each of the four 1RM tests. No injuries were reported during any of the 1RM tests. Paired-samples *t* tests revealed that strength increased for all exercises ($p \leq .17$).

Scores for the first 1RM test of ankle extension have been omitted because of faulty testing methodology used by two of the four data collectors. The faulty testing technique was discovered midway through the initial data collection period, after several subjects had already completed testing. Subjects tested by this method had inaccurate, low test scores. Testers were retrained on the procedure and performed the test correctly during the remaining trials.

Maximal Walking Speed

Figure 1 presents mean scores and standard errors for the experimental and control groups at pre-, mid-, and postintervention. A repeated measures ANCOVA, using the preintervention score as the covariate, revealed a significant between-group difference [$F(1,19) = 5.03, p < .05$]. A post-hoc paired samples *t* test demonstrated that the experimental group's mid- and postintervention walking speeds were both significantly better than the experimental group's preintervention walking speed ($p < .017$). These results are presented in Table 3.

5-Repetition Sit-to-Stand

Figure 2 presents mean scores and standard errors for the experimental and control groups at pre-, mid-, and postintervention. A repeated measures ANCOVA, using the preintervention score as the covariate, revealed no significant between-group difference [$F(1,19) = .068, p > .05$]. Planned comparisons (paired samples *t* tests) revealed that STS performance was significantly better at mid- and postintervention versus preintervention within the experimental group ($p < .017$). STS performance was significantly better at postintervention versus midintervention within the control group ($p < .017$).

Table 2. Experimental Group Biweekly Means (*SD*) of 1RM Scores (Pounds)

Exercise	Week 2	Week 4	Week 6	Week 8
	1RM	1RM	1RM	1RM
Leg extension	60 (24)	73 (28)*	78 (29)*	89 (34)***
Hip abduction	71 (21)	80 (21)*	82 (23)	85 (23)
Hip adduction	50 (15)	57 (15)*	57 (16)	63 (15)***
Gluteal press	108 (34)	127 (41)*	138 (49)	145 (46)
Leg press	185 (60)	204 (71)*	214 (72)**	229 (76)
Ankle extension	—	251 (70)	266 (76)**	284 (76)***

Notes: Data omitted due to faulty collection technique. 1RM = 1-repetition maximum.

* $p \leq .017$ vs Week 2; ** $p \leq .017$ vs Week 4; *** $p \leq .017$ vs Week 6.

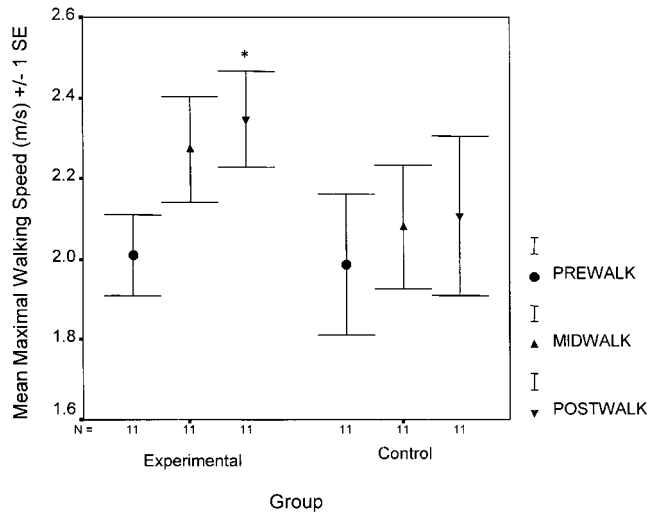


Figure 1. Maximal walking speed. * $p < .05$ versus control posttest.

1-Legged Blind Balance

Figure 3 presents mean scores and standard errors for the experimental and control groups at pre-, mid-, and postintervention. A repeated measures ANCOVA, using the pre-intervention score as the covariate, revealed no significant between-group difference post-intervention [$F(1,19) = .082, p > .05$]. Planned comparisons (paired samples t tests) revealed no significant within-in group changes ($p > .05$).

DISCUSSION

The purpose of this investigation was to examine the effect of a single exercise modality (strength training) on functional tasks related to the risk of falling in older adults. Several studies have examined the link between exercise and the incidence of falls among this older, at-risk population (13–15), but these studies have utilized multiple exercise modalities in their designs.

Effect of Training on Strength

Research has consistently demonstrated that, given a stimulus of sufficient intensity, muscle strength increases in older adults. The subjects in this study increased lower body strength an average of 20% to 48%, depending on the exercise (Table 2). These improvements are similar to changes reported by other researchers who trained their subjects at similar intensities (16–19), although greater gains have been reported (20,21). Also noteworthy is the fact that no injuries were reported during training or 1RM testing, which is consistent with the literature and reinforces the idea that intense strength training is safe and effective in older adults.

Table 3. Mean ($\pm SD$) Scores for Maximal Walking Speed (m/s) at Pre-, Mid-, and Postintervention

Group	Preintervention	Midintervention	Postintervention	% Change
Experimental	2.01 (0.33)	2.27 (0.43)*	2.35 (0.39)*	+17%
Control	1.99 (0.58)	2.08 (0.51)	2.11 (0.66)	+6%

* $p < .017$ vs experimental pre-intervention.

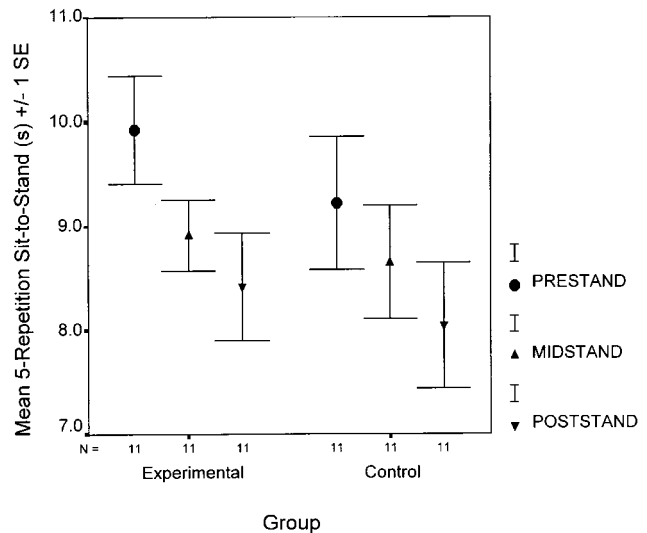


Figure 2. 5-repetition sit-to-stand time. No significant between-group difference posttest ($p > .05$).

The American College of Sports Medicine (ACSM) recommends that “older and more frail persons (approximately 50–60 yr [sic] of age and above)” should engage in weight training 2 to 3 days per week, at an intensity that allows completion of 10 to 15 repetitions (22). Typically, 10- to 15-repetition strength training involves lighter weights, which are appropriate for training muscle endurance. Our results, and a large body of literature that supports them, suggest that this recommendation is too conservative.

More impressive strength gains are seen when older adults train at higher intensities, and the risk of injury seems slight. Given appropriate medical clearance, there appears to be no reason that older adults cannot train intensely, following the same guidelines suggested by ACSM for other apparently healthy adults: “One set of 8–10 exercises that

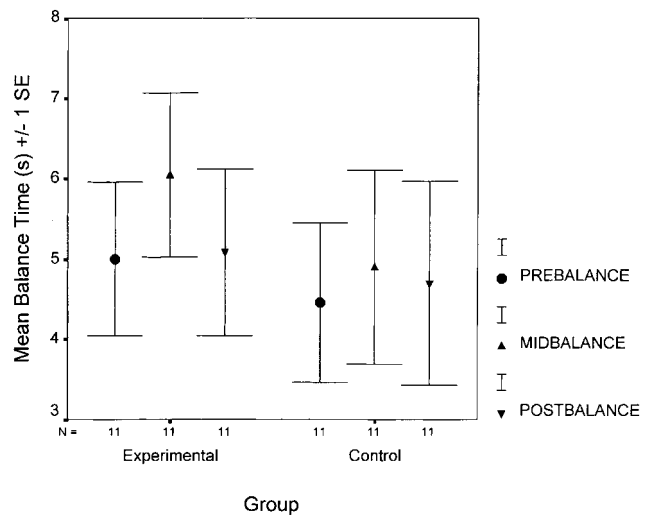


Figure 3. One-legged blind balance time. No significant between-group difference posttest ($p > .05$).

conditions the major muscle groups 2–3 d/wk. Most people should complete 8–12 repetitions of each exercise” (22).

Effect of Training on Walking Speed

These data showed that walking speed increased for both groups from pre- to mid- and from mid- to postintervention (Figure 1). The 17% increase in the strength-training group was significantly different from the 6% increase in the control group. Post hoc, paired samples *t* testing demonstrated a significant improvement within the training group but not within the control group pre- versus postintervention (Table 3). Our results suggest that lower-body strength training improves walking speed, a risk factor associated with falling.

The 17% improvement in walking speed seen in this study is in line with changes demonstrated by Fiatarone and colleagues (21) and Sipilä and colleagues (23). Both of these research groups witnessed a 12% increase in maximal walking speed after training groups of subjects aged 72 to 98 and 76 to 78 years, respectively.

Other studies evaluating the effect of strength training on walking speed have had mixed results, noting a 48% improvement in tandem walking speed (20), no change in usual walking speed (13,19), and a 14% decrease in backward walking speed in older adults (24). Different ways of measuring walking speed may be partly responsible for these varied results.

Effect of Training on Sit-to-Stand

Timed performance on the STS test improved for both the training and control groups from pre- to mid- and from mid- to postintervention (Figure 2). The 15% decrease in the time it took to complete five chair rises in the strength training group was not significantly different from the 13% decrease displayed by the control group. Post-hoc planned comparisons of within-group differences (paired samples *t* tests) demonstrated there was a significant improvement within the training group pre- to postintervention, as well as a significant improvement in the control group mid- to postintervention (Table 4). Our results suggest that something other than lower body strength gain accounts for the improvement in STS times, a risk factor associated with falling.

Another strength training study using a slightly higher training stimulus (80% 1RM) and similarly aged subjects (61–82 years old) found no effect of training on STS (19), and researchers using a less intense intervention (sand-bag ankle weights and fewer exercises) also reported no effect (25).

It is interesting that both groups in this study showed marked improvement in STS scores, suggesting that some measurement artifact was responsible for the change. Be-

cause this test involves rapid, repetitive movement that relies on controlling the center of mass, it is a novel activity and is unlikely to be performed in a normal environment. Therefore, repeated measure scores on sit-to-stand tests may be influenced by a powerful learning effect. Additional subject training prior to data collection may be warranted for sit-to-stand testing.

Effect of Training on Standing Balance

Single-leg blind balance time was not significantly different between the groups postintervention (Figure 3). Post-hoc planned comparisons of within-group differences (paired samples *t* tests) failed to reveal any significant changes in either group between pre-mid, pre-post, or mid-post intervention scores (Table 5). The large standard deviations for both groups at all testing periods indicate large variability among subjects. Similarly, the data were highly variable for each subject within and across the three testing periods. Our results suggest that lower body strength gain alone does not improve standing balance, a risk factor associated with falling.

Bohannon and colleagues (26) compiled single-leg blind balance scores from 184 people aged 20 to 79 years. They grouped their data by subjects' age (approximately 30 per group; each group representing one decade of life) and found that the mean score for people 60 to 69 years old was 10.2 ± 8.6 seconds. The mean score for people 70 to 79 years old was 4.3 ± 3.0 seconds.

The average age of subjects in our experiment was 72, and mean scores ranged from 4.46 ± 3.31 seconds to 6.05 ± 3.40 seconds (Table 5). Mean scores from our study were slightly higher than those recorded by Bohannon and colleagues, but the standard deviations were fairly similar.

Vellas and colleagues (27) studied single-leg balance (eyes open) in 512 community-dwelling older adults (73 ± 7.0 years of age) and found that 58% could maintain balance for at least 5 seconds. In our study, 55% of the subjects recorded at least one average test score ≥ 5 seconds. These comparisons suggest that our population was comparable to other populations of similar age in regards to single-leg balance ability.

There are few strength training intervention studies in the literature examining pre- and postintervention standing balance. Both Wolfson and colleagues (28) and Buchner and colleagues (13) found no significant interaction between strength training and balance, using low-intensity and intense training protocols, respectively. Data from this study support the hypothesis that strength training does not enhance standing balance.

Limitations

Interpretations of the findings are constrained by this study's limitations. The small sample size suggests that cau-

Table 4. Mean (\pm SD) Scores for 5-Repetition Sit-to-Stand Time (s) at Pre-, Mid-, and Postintervention

Group	Preintervention	Midintervention	Postintervention	% Change
Experimental	9.92 (1.72)	8.92 (1.13)*	8.42 (1.71)*	- 15%
Control	9.22 (2.1)	8.65 (1.8)	8.04 (2.02)**	- 13%

p* < .017 vs experimental preintervention; *p* < .017 vs control midintervention.

Table 5. (\pm SD) Scores for One-Legged Blind Balance (s) at Pre-, Mid-, and Postintervention

Group	Preintervention	Midintervention	Postintervention	% Change
Experimental	5.01 (3.18)	6.05 (3.40)	5.08 (3.46)	+1%
Control	4.46 (3.31)	4.90 (4.01)	4.70 (4.22)	+5%

Note: No significant within-group differences; *p* > .017.

tion should be taken before any generalizations are made, and sample homogeneity restricts generalization to Caucasian, physically active, highly motivated populations. Also, it is not possible to blind subjects to exercise interventions, leaving them vulnerable to a variety of tester and subject effects that may affect test results.

Conclusions

The present study has confirmed other work that suggests that older adults can undertake intense strength training without undo risk of injury and that intense strength training does increase strength in this population. However, it failed to clarify the relationship between strength gain and fall risk. Intense strength training appears to increase maximal walking speed but may not improve sit-to-stand ability or standing balance in active, community-dwelling older adults. Additional research into the unique effect of strength training on functional tasks related to the risk of falling needs to be completed.

One of the more notable, albeit anecdotal, findings of this study was the positive psychosocial boost that seemed to affect training subjects. Although this study design did not address psychological issues, almost every subject in the training group expressed profound appreciation for the beneficial nature of the exercise. Future research should consider combining quantitative and qualitative methods that not only examine the physiological changes that occur with strength training but also address the apparently positive (both in size and quality) psychological effects that strength training may provide. Much of this benefit may be attributed to interaction effects, but there appears to be a unique contribution that strength gain provides; many of the comments made by subjects were directly related to the augmented physical ability that resulted from improved strength.

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Address correspondence to Jeff Schlicht, PhD, Department of Physical Education, Western Connecticut State University, 181 White Street, Danbury, CT 06810. E-mail: schlichtj@wcsu.edu

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