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Effects of Strength Training on Physical Function: Influence of Power, Strength, and Body Composition

Erik D. Hanson,[1] Sindhu R. Srivatsan,[1] Siddhartha Agrawal,[1] Kalapurakkal S. Menon,[1] Matthew J. Delmonico,[1,2] Min Q. Wang,[1] and Ben F. Hurley[1]

[1]*Department of Kinesiology, School of Public Health, University of Maryland, College Park, Maryland; and* [2]*Department of Kinesiology, University of Rhode Island, Kingston, Rhode Island*

Abstract

Hanson, ED, Srivatsan, SR, Agrawal, S, Menon, KS, Delmonico, MJ, Wang, MQ, and Hurley, BF. Effects of strength training on physical function: influence of power, strength, and body composition. *J Strength Cond Res* 23(9): 2627–2637, 2009—The purpose of this study was to determine (a) the effects of strength training (ST) on physical function and (b) the influence of strength, power, muscle volume (MV), and body composition on physical function. Healthy, inactive adults ($n = 50$) aged 65 years and older underwent strength, power, total body composition (% fat and fat free mass [FFM]), and physical function testing before and after 22 weeks of ST. Physical function testing consisted of tasks designed to mimic common physical activities of daily living (ADL). To improve internal validity of the assessment of mid-thigh intermuscular fat, subcutaneous fat, and knee extensors MV, a 10-week unilateral ST program using the untrained leg as an internal control preceded 12 weeks of whole-body ST. Strength, power, and FFM increased significantly with ST (all $p < 0.05$), whereas rapid walk, 5 chair stands, and get up and go time decreased significantly with ST in the overall group (all $p < 0.05$). Women improved significantly in both walking test times (both $p < 0.05$) but not in the stair climb test, whereas men improved in the stair climb test ($p < 0.05$) but not in walking test times. Multiple regression analysis revealed the highest R^2 (0.28) for the change in chair stands time, followed by stair climb and usual walk at 0.27 and 0.21, respectively. ST improves performance in functional tasks important for ADLs. Changes in strength, power, and FFM are predictors of ST-induced improvements in these tasks.

Key Words resistance training, aging, activities of daily living

Address correspondence to Ben F. Hurley, benhur@umd.edu.

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Introduction

The loss of muscle mass with age (sarcopenia) is associated with a decline in muscle strength (21), muscle power (23), muscle quality (21), and physical function (26) and increases in fat infiltration (36) and mortality (24). Power and strength are key predictors of functional performance and disability (1,2,6,12,20,22,35). Age-associated changes in body composition, muscle mass, and fat infiltration are also related to mobility deficits (19,36,37).

Strength training (ST) is recommended as the intervention of choice for the prevention and treatment of the adverse consequences of sarcopenia (15,29). This conclusion is based on an abundance of studies showing that ST improves muscular strength, power, and body composition (total and regional) (7,8,12–14,25,27,28,32–34). Numerous studies have demonstrated that ST can improve physical function (8,11–13,25,34), but rarely have the specific physical attributes most responsible for this improvement been addressed. Previous attempts to link associations between specific physical attributes and physical function have the usual limitations of cross-sectional designs (1,2,19,20,22,30,38). However, the few studies available on this association provide no direct evidence that the improved physical function is the result of increased anaerobic power or other physical attributes. Identifying specific physical attributes that improve specific tasks would be useful to older adults at risk for disability.

Some investigators have concluded that muscle power, muscle strength, and body fat are predictive of physical function and disability. Several reports indicate that leg power explains a larger portion of the variation within physical function performance than does leg strength in older men and women (2,13,22). In the absence of power measurements, strength alone was a significant predictor of performance in functional tasks (4,20) and walking and repeated chair stand performance was slowest in older adults who possessed the lowest strength levels and in those with the greatest levels of fat infiltration (35). However, when strength and fat were compared for their relationship to function, estimated by physical performance scores, it was concluded that fat mass

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rather than strength was the best predictor of physical disability (19). The few published studies that correlate change in physical function with change in physical attributes present conflicting results (4,5,13). These studies provide important insights into which physical attributes may be important for performance in functional tasks commonly experienced by older adults. The associations observed between these physical attributes and physical function provide support to the hypothesis that improvements in strength, power, and body composition as a result of ST will predict improvements in specific tasks related to physical function. Nevertheless, there is insufficient and conflicting information in the existing literature to determine if ST-induced improvements in power, strength, and body composition will predict improvements in functional abilities. In addition, no information has been reported on the combination of physical attributes that best predict ST-induced improvements in physical function.

The primary purpose of this study was to examine the effects of ST on specific physical function–related tasks and the predictive influence of changes in power, strength, and body composition with ST on improvements in standardized tests of common physical activities of daily living (ADL) in older adults. By combining previously established predictors of physical function and analyzing them independently and collectively, we tested the following primary hypothesis: ST will improve performance in tests of physical function, with improvements in muscle power being the strongest predictor, followed by muscle strength and then body composition. Furthermore, we hypothesize that the combination of multiple variables will result in better models than the single predictors alone. Our secondary hypothesis is that ST-induced increases in muscle volume (MV) and decreases in subcutaneous fat (SCF) and intermuscular fat (IMF) during the early phase of training will significantly improve the prediction of physical function in the same hierarchical order as power, strength, and body composition.

Methods

Experimental Approach to the Problem

ST has previously been shown to improve power, strength, and body composition. In turn, improvements in these variables have been associated with improvements in physical function. However, the specific variables or combination most responsible for the improvement in physical function remain unclear because the comparison of all such variables have not been reported previously within a single study. Older men and women were studied to determine the predictive power of ST-induced changes in peak muscle power, strength, and body composition on improvements in physical function.

Subjects

Eighty-one healthy and sedentary men ($n = 35$) and women ($n = 46$) ages 65 to 85 years volunteered to participate in the study. Sedentary was defined as not having participated in a regular exercise program for more than 20 minutes 1 time per week. None of the subjects had participated in an ST program in the 6 months preceding enrollment in the study. Of the 81 subjects who completed baseline testing, 50 (23 men and 27 women) completed all follow-up testing. Some subjects failed to complete the protocol after phase 1 ($n = 8$) or as a result of unspecified lack of interest ($n = 9$), pain and discomfort from pre-existing conditions ($n = 9$), attendance and time commitment ($n = 3$), or injury unrelated to the study ($n = 2$). An additional 9 subjects (3 men and 6 women) served as a nonexercise control group. The control group underwent the same 5 physical function tests as the training group at similar time intervals. Table 1 shows the physical characteristics of the ST and control subjects at baseline (before phase 1 ST). There were no significant differences between groups for age, height, body mass, or body mass index (BMI).

All subjects underwent an initial phone screening interview, completed a detailed medical questionnaire, and received medical clearance from their primary care physician. Subjects were nonsmokers who were free of neuromuscular, cardiovascular, or metabolic disorders that may have affected their ability to safely perform high-intensity ST. Any subjects who were taking medication were required to maintain the dosage throughout the study. Subjects were also instructed to maintain their regular physical activity levels and dietary habits. After all methods and procedures were explained, subjects read and signed the informed consent, which was approved by the University of Maryland Institutional Review Board.

Table 1. Physical characteristics of the strength-trained (ST) and control groups.

	ST ($n = 50$)	Control ($n = 9$)
Age (years)		
Overall	71 (5)	67 (10)
Men	71 (4)	64 (9)
Women	71 (5)	69 (11)
Height (cm)		
Overall	166.8 (9.0)	164.8 (8)
Men	174.0 (6.4)	174.1 (3)
Women	160.7 (5.8)	160.2 (5)
Body mass (kg)		
Overall	80.4 (14.5)	74.4 (16)
Men	86.4 (12.3)	82.9 (9)
Women	75.5 (14.4)	69.3 (17)
BMI (kg/m^2)		
Overall	28.8 (4.4)	26.8 (4)
Men	28.4 (2.9)	27.4 (4)
Women	29.2 (5.3)	26.5 (5)

Values are means (*SD*).
BMI = body mass index.

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Procedures

Body Composition. Body composition (% fat and fat-free mass [FFM]) was estimated at baseline, after 10 weeks of unilateral training (phase 1), and after 12 weeks of whole-body (WB) training (phase 2) by dual-energy X-ray absorptiometry (DEXA_) using fan-beam technology (model QDR 4500A, Hologic, Waltham, Massachusetts, U.S.A.) using previously described procedures (7). The coefficients of variation (CV) for all DEXA measures of body composition were calculated from repeated scans of 10 subjects who were scanned 3 consecutive times with repositioning. The CV was 0.6% for FFM and 1.0% for % fat (7). The scanner was calibrated daily against a spine calibration block and step phantom block supplied by the manufacturer. In addition, a whole-body phantom was scanned weekly to assess any machine drift over time.

Mid-Thigh Subcutaneous Fat, Intermuscular Fat, and Muscle Volume of the Knee Extensors. To quantify SCF, IMF, and MV, computed tomography (CT) imaging of the trained and untrained thighs (GE Lightspeed Qxi, General Electric, Milwaukee, Wisconsin, U.S.A.) was performed at baseline and during the final week of the unilateral ST program using previously described methods (39). The CT equipment, section thickness, and imaging procedure were the same for all MV, SCF, and IMF measurements. For each SCF scan, the technician manually outlined the entire mid-thigh and the deep fascial plane surrounding the thigh muscles. SCF was assessed by subtracting the area inside the deep fascial plane from the entire area of the mid-thigh. The IMF was distinguished from the SCF by manually drawing a line along the deep fascial plane surrounding the thigh muscles with the exclusion of bone marrow fat (9). The IMF was then segmented into a separate image, in which it was identified based on Hounsfield Units where IMF ranged from −190 to −30, as previously described (9).

Final MV was calculated using the truncated cone formula as reported by Tracy et al. (31). To calculate MV, the cross-sectional area (CSA) of the knee extensor (KE) muscle group was manually outlined every 40 mm from the first section closest to the superior border of the patella to a point where the KE muscle group was no longer reliably distinguishable from the adductor and hip flexor groups. CV was calculated using repeated measures of selected axial sections of 1 subject on 2 separate days. Signifying within-investigator reliability, average intra-investigator for SCF CSA CV was 0.86%, IMF was less than 5%, and MV CV was 1.6%.

Training-induced changes were calculated by subtracting the differences between pre- and post-test measures in the control leg from those in the trained leg. Measurements in the untrained leg served as a control for variation of MV, SCF, and IMF CSA as a result of seasonal, methodological, motivational, attention, biological, and genetic factors.

Muscle Strength. KE 1 repetition maximum (1RM) strength tests were performed at baseline and after phase 1 and phase 2 of the ST program using Keiser A-300 air powered machines (Keiser Co. Inc., Fresno, California, U.S.A.) via standardized protocols described previously (7). The 1RM was achieved by gradually increasing the resistance from an estimated submaximal load after each successful exercise repetition until the maximal load was obtained for each exercise. Prior to baseline 1RM testing, 2 familiarization sessions were performed with light resistance. The familiarization sessions helped to familiarize the subjects with the equipment, to help control for the large 1RM strength gains that commonly result from skill (motor learning) acquisition during the initial stages of training, and to help prevent injuries and reduce muscle soreness following the strength testing protocol.

The leg press 1RM was obtained following phase 1 and again after phase 2 using a Keiser air-powered leg press. To minimize the effects of strength gains from phase 1 KE training from phase 2 training, the untrained leg from phase 1 training was used to assess the effects of WB training on leg press strength. A familiarization session preceded the testing session. Leg press 1RM was achieved in an identical manner to the KE 1RM test.

Muscle Power. KE peak power testing was performed at baseline and after each phase of ST on a Keiser A-430 air-powered machine designed specifically for muscle power assessment using methods described previously (7). Following a 30-second rest period after the warm-up, subjects performed 3 power tests on each leg alternating between right and left at 50, 60 and 70% of their 1RM, with a 30-second rest period between each of the 3 trials and 2-minute rest periods between each increase in resistance. An attempt was made to find an absolute load that could be replicated from baseline testing. This typically occurred at 70% of 1RM at baseline and at 50 or 60% of 1RM after ST. If no load could be found that replicated the baseline load, an additional set was performed during the after-ST test using 50% of the baseline 1RM to obtain a replicated trial. If multiple loads were replicated, the smallest loads were always used. The peak value was obtained within each individual trial. To determine the overall peak power for each load, the highest value among the 3 trials was selected. The difference between the values was the change in power with ST. Data for each repetition were passed through a zero-phase forward and reverse digital filter designed using MatLab version 6.0.5 (Math Works Inc., Natick, Massachusetts, U.S.A.) to remove sensor noise prior to determining the peak power. A low-pass, tenth-order Butterworth filter with a cutoff frequency of 10 Hz was used.

Physical Function Tasks. All physical function tasks were tested at baseline and after phase 2 ST. Prior to performing each task, the task was explained in detail, a demonstration was provided, and subjects were given the opportunity to perform a practice repetition. The use of any assistive devices by subjects was recorded for each trial. Trials were completed in

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duplicate. The faster of the 2 trials was recorded to the nearest 0.1 second.

6-m Walks. Walking speed was assessed by measuring the time it took subjects to cover a 6-m course at their habitual and maximal walking speeds, as described previously (13). In addition, they walked to a mark 1.25 m beyond the 6-m line to avoid bias from deceleration. The rest interval between trials and between the usual and rapid 6-m walk tests was 30 seconds.

Five Chair Stands. A hard-seated, straight-backed, armless chair that was 43 cm in height was used to evaluate 5 chair stand performance in methods previously described (13). The task began with the subject seated and arms folded across the chest. The subjects were required to perform 5 chair stands. To count as a complete repetition, subjects were required to stand fully and to sit completely. This was monitored visually by the investigators. The time was stopped when subjects finished standing during the fifth repetition. The rest interval between trials was 3 minutes.

Get Up and Go. The 43-cm chair used in the chair stands test was again used in the get up and go test. The methods were identical to those described previously (13). In this task, subjects were required to rise from a seated position, walk 2.44 m (8 feet) around a cone, and return to the seated position. The rest interval between trials was 1 minute.

Stair Climb. Stair climbing ability was assessed by timing subjects as they climbed 1 flight of 9 stairs. Each step was 19 cm in height. The standardized starting position for each subject was 1 foot length back from the first step. Subjects were required to place at least 1 foot on each step, and no skipping of steps was permitted. The rest interval between trials was 1 minute.

ST Program. The ST program consisted of 2 phases. The first phase consisted of ~10 weeks (30 sessions) of unilateral ST, and the second phase immediately followed the first phase and consisted of ~12 weeks (36 sessions) of WB ST. The first phase consisted of training the KE of the dominant leg 3 times per week at near-maximal effort on all repetitions. As we previously described in detail (7), the protocol was designed to combine heavy resistance with high volume while eliciting near-maximal effort on all repetitions. This training protocol has proved to be effective in increasing KE strength and MV in men and women of similar age of those in the present study (7,16,17,31,40). Training was performed on a Keiser A-300 air-powered KE machine, which allowed for ease of changing the resistance without interrupting the cadence of the exercise. The untrained leg was kept in a relaxed position throughout the training program and was used as an internal control for variations because of methodology (e.g., testing procedures), biological drift, seasonal drift, genetic factors, and drift in values resulting from attention and motivation.

Following a light warm-up (~2 minutes) on a stationary bicycle, the unilateral ST protocol consisted of 5 sets of KE exercise for those <75 years of age and 4 sets for those ≥75 years of age. Subjects ≥75 years of age did not perform the last set because of concern that 50 repetitions at near-maximal effort for this age group would cause overtraining, possibly resulting in a reduction of strength gains. The first set was considered a warm-up set and consisted of 5 repetitions at 50% of the previously determined 1RM strength value. This set was used primarily to minimize the risk of injury imposed by the subsequent heavy resistance sets. The second set consisted of 5 repetitions at the current 5RM value. The 5RM value was originally set to 85% of the 1RM and was increased continually throughout the training program to reflect increases in strength. The first 4 to 5 repetitions of the third set were performed at the current 5RM value, then the resistance was lowered just enough to complete 1 or 2 more repetitions before reaching muscular fatigue. This process was repeated until a total of 10 repetitions were completed. This same procedure was used for the fourth and fifth sets, but the total number of repetitions was increased in these sets to 15 and 20, respectively. The

TABLE 2. Strength-training (ST) protocols for phase 1 and 2.

Phase 1 ST	Phase 2 ST
Warm-up set: 5 repetitions at 50% of 1RM	Warm-up set: 5 repetitions at 50% of 1RM
30 seconds rest	30 seconds rest
Set 2: 5 repetitions at 5RM	Set 2: 15 repetitions at 5RM*
90 seconds rest	
Set 3: 10 repetitions at 5RM*	
150 seconds rest	
Set 4: 15 repetitions at 5RM*	
180 seconds rest	
Set 5: 20 repetitions at 5RM*	

1RM = 1 repetition maximum.

Phase 1 ST consisted only of single-leg knee extensors (KE). Phase 2 ST consisted of KE, chest press, seated row, seated leg curl, abdominal crunch, and alternating leg press.

*The first 4 to 5 repetitions of the set were performed at the current 5RM value, then the resistance was lowered just enough to complete 1 or 2 more repetitions before reaching muscular fatigue. This process was repeated until all required repetitions for the set were completed.

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second, third, fourth, and fifth sets were preceded by rest periods lasting 30, 90, 150, and 180 seconds, respectively (Table 2). The resistance was adjusted accordingly within the set and for the following training session to ensure each repetition was performed using the proper resistance and form through the full range of motion.

The second phase of the ST program consisted of WB training, designed to target all major muscles groups in the body, and was performed 3 times per week for ~12 weeks. Exercises included KE, chest press, seated row, seated leg curl, abdominal crunch, and alternating leg press. All WB exercises were performed using Keiser air-powered machines. As in phase 1, a light warm-up set of 5 repetitions at 50% of estimated 1RM was performed, followed by a single training set of 15 repetitions starting at the 5RM (Table 2). After completing the initial 5 repetitions, resistance was lowered just enough to complete 1 to 2 additional repetitions. The shortening (formerly concentric) and lengthening (formerly eccentric) phases of all exercises were performed in approximately 2 and 3 seconds, respectively. Similar to phase 1, the resistance was progressively increased as subjects increased their strength such that the 5RM level of resistance was maintained for all exercises. Trained research assistants provided 1-on-1 supervision for all training sessions in both phases of the training program. The attendance compliance for phase 1 was 93.3 ± 1.3% and 87.6 ± 1.1% for phase 2.

Statistical Analyses

All statistical analysis was performed using SAS software (SAS version 9.1, SAS Institute, Cary, North Carolina, U.S.A.). Repeated-measures analyses of variance (ANOVA) were conducted with a between-subjects factor, sex, for KE 1RM, leg press 1RM, power, % fat, and FFM. Pre-planned post hoc analysis included separate paired *t*-tests for men and women to examine their response to ST separately. Repeated-measures ANOVAs with between-subjects factors of sex and group were used to analyze changes in functional task performance with ST between and within groups. Post hoc analysis again included paired *t*-tests within each group for both men and women. Statistical significance was set at $p < 0.05$ for all ANOVAs and *t*-tests. Multiple regression models were constructed using a backward elimination technique. The dependent variables in all regression models were the changes in physical function task times. Statistical significance was set at $p < 0.10$ for all regression variables and models because of the lack of orthogonality of the independent regression variables.

Power Analysis

The statistical power for all physical function regression analyses was calculated. The analysis revealed that the stair climb task power was highest, 0.978 ($n = 45$), followed by chair stands at 0.956 ($n = 42$), usual walk at 0.891 ($n = 46$), and get up and go at 0.639 ($n = 36$). Rapid walk regression analysis had the lowest statistical power at 0.583 ($n = 45$).

Results

Muscle strength, power, and body composition at baseline and after the phase 2 ST program are displayed in Table 3. When all subjects were combined, there were significant increases in KE strength ($p < 0.01$), leg press strength ($p < 0.01$), KE power ($p < 0.01$), and FFM ($p < 0.01$) with ST. Men showed significantly greater increases in KE strength than women ($p < 0.05$), but no significant differences between

Table 3. Knee extensor (KE) strength, leg press strength, KE power, and body composition at baseline and after strength training (ST).

	Baseline	After ST
KE 1RM (kg)		
Overall ($n = 48$)	22 ± 1	28 ± 1†
Men ($n = 21$)	29 ± 1	37 ± 1†‡
Women ($n = 27$)	17 ± 1	22 ± 1†
Leg press (kg)		
Overall ($n = 46$)	88 ± 3	96 ± 3†
Men ($n = 20$)	107 ± 3	115 ± 3†
Women ($n = 26$)	71 ± 3	82 ± 3†
Power (watts)		
Overall ($n = 37$)	279.7 ± 17.7	330.2 ± 18.6†
Men ($n = 16$)	371.9 ± 18.6	432.3 ± 16.0†
Women ($n = 20$)	205.9 ± 12.9	248.5 ± 13.8†
Body fat (%)		
Overall ($n = 46$)	34.8 ± 1.3	34.4 ± 1.1
Men ($n = 20$)	29.4 ± 1.0	29.1 ± 1.0
Women ($n = 26$)	40.2 ± 1.1	39.7 ± 1.0
FFM (kg)		
Overall ($n = 46$)	49.8 ± 1.4	50.4 ± 1.5†
Men ($n = 20$)	58.3 ± 1.5	59.4 ± 1.5*
Women ($n = 26$)	42.8 ± 1.2	43.2 ± 1.3

Values are means ± standard error.

KE 1RM = 1 repetition maximum of knee extensors; leg press = 1 repetition maximum of single leg press; Power = peak power of knee extensors; FFM = fat free mass.

*Significantly different from baseline ($p < 0.05$).

†Significantly different from baseline ($p < 0.01$).

‡Δ after ST significantly different from women ($p < 0.05$).

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sexes were observed for leg press strength, power, body fat, or FFM. Men increased their FFM significantly ($p < 0.05$), but women did not.

MV, IMF, and SCF are shown in Table 4. As expected, the increase in MV with ST in the trained leg was significantly greater than the untrained leg in both men and women and when groups were combined ($p < 0.01$), but men experienced a significantly greater increase in absolute terms than women ($p < 0.05$). The only other sex difference was a significantly greater decrease in SCF in the trained leg of women compared to men ($p < 0.05$).

Table 5 provides the physical function task times. When men and women were combined, task times were significantly faster after ST in the 6-m rapid walk ($p < 0.01$), 5 chair stands ($p < 0.01$), and get up and go ($p < 0.01$), whereas 6-m usual walk time only approached significance ($p = 0.065$). There were no significant sex differences in response to ST in any of the tasks, despite a few cases in which 1 group improved significantly and the other did not. Only women improved significantly ($p < 0.05$) in 6-m usual walk time, whereas in the stair climb, only men significantly improved their performance ($p < 0.05$). In the 6-m rapid walk, the women significantly improved their performance ($p < 0.01$), whereas the men only approached significance ($p = 0.06$). In the control group, the only significant change from baseline in the overall group was in the 6-m usual walk time, which was significantly slower during the second test ($p < 0.05$). Women only in the control group had a significantly slower performance in the get up and go task

TABLE 4. Muscle volume, intermuscular fat, and subcutaneous fat changes with strength training (ST) in the trained and untrained legs.

	Δ Trained leg	Δ Untrained leg
MV (cm^3)		
Overall ($n = 47$)	1136 ± 71*	−27 ± 65
Men ($n = 22$)	1338 ± 118*†	−65 ± 113
Women ($n = 25$)	958 ± 69*	−108 ± 67
IMF (cm^2)		
Overall ($n = 47$)	−0.67 ± 1.49	−0.22 ± 1.37
Men ($n = 22$)	−1.26 ± 1.58	−1.76 ± 1.40
Women ($n = 25$)	−2.71 ± 2.46	−1.97 ± 2.23
SCF (cm^2)		
Overall ($n = 46$)	−171.5 ± 65.4	−153.9 ± 55.9
Men ($n = 20$)	−16.0 ± 99.1†	−141.3 ± 77.4
Women ($n = 26$)	−291.2 ± 80.9	−163.5 ± 80.2

Values are means ± standard error.
MV = muscle volume; IMF = intermuscular fat; SCF = subcutaneous fat.
Δ Trained leg = after ST value − baseline value for trained leg.
Δ Untrained leg = after ST value − baseline value for untrained leg.
*Significantly different than the Δ in the untrained leg ($p < 0.01$).
†Δ in the trained leg significantly different from women ($p < 0.05$).

TABLE 5. Physical function task times at baseline and after strength training (ST) in trained and control subjects.

	ST		Control	
	Baseline	After ST	Baseline	After ST
6-m usual walk (sec)				
Overall ($n = 50$)	5.4 ± 0.1	5.2 ± 0.2‡	5.5 ± 0.3	5.9 ± 0.3*
Men ($n = 23$)	5.1 ± 0.1	5.1 ± 0.2	5.1 ± 0.4	5.7 ± 0.5
Women ($n = 27$)	5.7 ± 0.2	5.3 ± 0.2*	5.5 ± 0.4	5.9 ± 0.4
6-m rapid walk (sec)				
Overall ($n = 49$)	3.9 ± 0.1	3.7 ± 0.1†‡	4.0 ± 0.3	4.1 ± 0.3
Men ($n = 23$)	3.6 ± 0.1	3.5 ± 0.1	3.4 ± 0.2	3.6 ± 0.3
Women ($n = 26$)	4.2 ± 0.1	3.9 ± 0.1†	4.3 ± 0.3	4.4 ± 0.4
5 Chair stands (sec)				
Overall ($n = 49$)	9.2 ± 0.3	7.9 ± 0.3†	9.9 ± 1.5	10.2 ± 2.0
Men ($n = 22$)	8.4 ± 0.4	6.8 ± 0.3†	8.9 ± 1.6	7.9 ± 1.0
Women ($n = 27$)	9.8 ± 0.4	8.7 ± 0.4†	11.0 ± 2.6	11.3 ± 2.9
Get up and go (sec)				
Overall ($n = 48$)	5.7 ± 0.1	5.2 ± 0.2†‡	5.5 ± 0.4	5.9 ± 0.6
Men ($n = 22$)	5.3 ± 0.2	4.8 ± 0.2†	4.6 ± 0.4	4.6 ± 0.4
Women ($n = 26$)	6.1 ± 0.2	5.6 ± 0.2†	6.0 ± 0.6	6.5 ± 0.7*
Stair climb (sec)				
Overall ($n = 50$)	4.6 ± 0.2	4.5 ± 0.2	4.5 ± 0.5	4.8 ± 0.6
Men ($n = 23$)	4.1 ± 0.2	3.8 ± 0.2*	3.5 ± 0.5	3.6 ± 0.2
Women ($n = 27$)	5.1 ± 0.2	5.1 ± 0.3	5.4 ± 0.9	5.5 ± 1.0

Values are means ± standard error.
*Significantly different than baseline ($p < 0.05$).
†Significantly different than baseline ($p < 0.01$).
‡Δ after ST significantly different from control group ($p < 0.05$).

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Table 6. Regression coefficients for physical function tasks.

	Estimate ± *SE*	R^2	*p*-value
6-m usual walk (*n* = 46)		0.21	0.018
FFM	−0.138 ± 0.064		
Sex	−0.538 ± 0.229		
Race	0.699 ± 0.301		
6-m rapid walk (*n* = 45)		0.07	0.087
FFM	−0.068 ± 0.039		
5 Chair stands (*n* = 42)		0.28	0.006
% Fat	0.798 ± 0.238		
Fat	−0.820 ± 0.224		
IMF	0.079 ± 0.033		
Get up and go (*n* = 36)		0.10	0.062
Power	−0.004 ± 0.002		
Stair climb (*n* = 45)		0.27	0.001
FFM	−0.199 ± 0.059		
KE 1RM	−0.110 ± 0.049		

SE = standard error; FFM = fat-free mass; IMF = intermuscular fat; KE 1RM = knee extensors 1 repetition maximum; Fat = fat mass; % Fat = percent body fat.

($p < 0.05$). When the changes from baseline to after ST between groups were examined, the improvement of the ST group was significantly greater than that of the control group for the 6-m usual and rapid walks and get up and go (all $p < 0.05$).

Regression models were constructed using the changes in power, strength, and body composition to predict the changes in physical function task time with ST. Visual examination of the plots depicting the changes in physical function task time with the change in each of the independent variables revealed no evidence of a curvilinear or quadratic relationship, which have been reported in previous studies (2,6). Separate models were constructed for all of the physical function tasks, and the results of the analysis are displayed in Table 6. All predictor variables included in Table 6 were significant ($p < 0.10$). In the regression model for the 6-m usual walk, the final model included sex as a predictor variable ($p < 0.05$), as might be expected because women significantly improved walk time and the men did not. However, in the 6-m rapid walk and stair climb tests, sex was neither significant nor included in the final model despite the fact that the women and men improved differently in the respective tasks.

Discussion

The findings of this study support the hypothesis that ST improves physical functioning in older adults and that ST-induced increases in power, strength, and FFM are significant predictors of improved physical functioning in specific tasks. However, our results did not support the hypothesis for a preferential order of influence of muscle power, strength, and FFM, respectively. Moreover, combinations of these predictors explain only a small to moderate portion of the variations in the change in physical function. Sex and race combined explained an additional portion of the variability. The secondary hypothesis that MV, IMF, and SCF will add predictive strength to the regression models was supported only in the chair stands. There also was no preferential order of importance for MV, IMF, and SCF. These results suggest that the efficacy of ST to improve functional abilities may at least partially depend on the extent to which the ST program leads to improvements in power, strength, and body composition.

Our ST protocol produced mixed findings with respect to improvements in physical function, which are supported by some investigators (4,8,12,13) and not by others (8,11,34). However, improvements in individual functional tasks are inconsistent, both within the current study and between other studies. For example, the ST program significantly improved performance in the 6-m rapid walk time, which was supported by some (8,12) but not by others (8,11). Galvão and Taaffe (8) reported that rapid walk time was associated with an ST program that used a single set training, whereas multiple sets were used in the studies showing no improvements (8,11). However, the opposite associations were observed with the 6-m usual walk time. Usual walk time was not significantly improved in the current study for the overall group, and this finding was confirmed in another study of older adults performing only a single set of ST (8), whereas older adults who performed multiple sets did improve walk performance (8,11,12). The general lack of consistent results may be because of the relatively small degree of improvement, typically less than 10%, observed in the present study and in other studies. Nevertheless, it is unclear whether any of these findings are related to the number of sets used in the respective training programs. In the present study, only 1 set was used after the initial 10 weeks of multiple sets of unilateral KE training. We are not aware of any data available that address the question of whether the effects of ST on functional performance are influenced by the number of sets, but it is unlikely that this factor alone would explain effects on functional outcomes, independent of total exercise volume, number and type of exercises, or level of resistance used.

Chair stands and get up and go performance significantly improved with ST. These findings agree with previously published reports (4,13), although the magnitude of change is less in the present study. The large age difference between the study populations and the faster baseline times (indicative of higher functioning) of our participants are likely contributors to the differences in improvement. Stair climb performance overall and particularly in women failed to improve significantly with ST in the present study, consistent with 1 (12) report, although conflicting with other reports (8,34). Of note, the low-intensity group and the single-set group had

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nonsignificant trends showing greater improvement than the high-intensity and multi-set groups (8,34). The reasons for the differences between intensity, number of sets, and in our case sex remain unknown. However, because men experienced greater gains in KE 1RM than women and 1RM improvement significantly predicts improvement in stair climbing ability, this may at least partially explain the sex differences in stair climb performance in our results.

The improvements in physical function with ST and the specific attributes that account for these changes reported by others present conflicting results. Several studies provide evidence that improvements in strength, power, or body composition explain improvements in physical function (5,13,34), whereas other studies refute these findings (4,25). In the absence of a change in body weight and therefore the amount of work necessary to complete the task, the improvements in stair climbing ability were attributed to gains in strength (34). Gains in strength were also associated with mobility, gait speed, and chair rise performance after Theraband training (5). When strength and power were compared, only changes in average power were significantly correlated with physical function (13). In a separate study where power training protocols (faster velocity) were compared with conventional ST, the power-trained subjects had higher continuous scale physical function performance scores (CS-PFP), despite performing less total work (25). However, the improvements in physical function did not significantly correlate to the change in peak anaerobic power or leg press strength. It has been suggested that faster-velocity ST may result in greater gains in neural adaptation than conventional ST (11), possibly explaining the different response. Although other investigations linked power and strength to improved functioning, our results favor improvements in FFM because 3 of the 5 regression analyses included FFM. The small increase in FFM accompanied by a trend toward reductions in % fat contributed to no significant change in body weight. Thus, the improvement in function may be the result of a more favorable body composition. Of interest, gains in KE strength and power were not significantly correlated with total body FFM. Only when changes in FFM were parceled out into upper- and lower-body FFM gains did a relationship appear with KE strength. Because of the lack of significant correlations among power, strength, and FFM, it is difficult to determine exactly how the increases in FFM are improving function.

Few studies have addressed the importance of neural adaptations that occur with ST, which may make an important contribution toward improving physical function, given their important role in strength gains with ST (10). The initial gains in strength and function are often the result of increased muscle coordination or decreased agonist–antagonist co-contraction. Because electromyography data were not collected, neural adaptations and muscle activity changes could not be assessed. This may be 1 reason why the regression models only explain marginal to moderate portions of the variability in physical function. Other investigators have concluded that in well-functioning older adults, a ceiling effect may be present with respect to physical functioning (8,12) and that improvements in strength and power beyond a certain threshold do not continue to improve functional performance. This could also explain the current lack of strong relationships between changes in muscle function and physical function. The studies that demonstrated the largest gains in physical function had older subjects (mean age = 80+ years) who displayed low levels of physical function, even after exercise interventions (4,13). Our subjects had relatively high levels of physical function, based on the notion of a ceiling effect, and may also at least partially explain some of the inconsistencies in changes in physical function with ST.

The current study showed no significant decline in SCF or IMF with ST. This may be why only 1 of our functional measures was associated with them. However, maintaining normal body fat is important for the elderly because high fat levels are associated with metabolic disorders, reductions in strength, and functional disabilities (9,19,36–38). Reports are mixed on the effects of ST on total and regional fat mass. Previous data from our lab show reduced IMF levels in older adults with ST, with these reductions being genotype dependent (40). Despite no significant change in IMF and in conjunction with the changes in % fat and total fat, the 3 variables collectively are a significant predictor of chair stand performance. Although none of the fat-related variables changed significantly with ST, there appears to be a joint relationship between them and the improvement in chair stand performance. In other studies, ST was as effective as aerobic exercise training for reducing SCF in upper- and lower-body regions when both training modalities were combined with a controlled diet (27,28). Moreover, significant reductions in arm, leg, and trunk fat and total body fat mass have been reported (33), as have significant reductions in intra-abdominal and total adipose tissue and mid-thigh SCF in older adults (14,32). In contrast, ST may not change trunk, intra-abdominal, or SCF mass with ST in young and old men and women (3,18). The current study was not designed to induce weight loss because subjects were required to maintain their usual caloric intake. Furthermore, our ST protocol was a relatively low caloric expenditure, which was sufficient to improve strength, power, and function but not to decrease SCF or IMF. Therefore, the lack of changes in SCF and IMF was not unexpected and our results indicate that they are not essential to improve function with ST in older adults. Our finding of no significant association between the changes in MV and physical function was supported by some cross-sectional studies (36,38) but not others (35,37). However, this finding was also not totally unexpected because KE MV was measured only prior to and after phase 1.

The single-leg training protocol used in phase 1 of the present study tests the independent effects of ST on local fat

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reduction and its effects on changes in physical function. Because none of the previous investigators who reported ST-induced reductions in total or regional fat adequately controlled for dietary and other possible intervening factors that could influence results, we used the single-leg protocol, comparing the trained and untrained leg, both of which were subject to identical dietary effects. Consequently, the design of the current study, for the first time, controls for dietary influences. The use of the untrained leg also controls for normal drift in values as a result of deviations in methodology, biology, seasonal variation, genetic factors, and variations in attention and motivation between experimental and no-exercise control groups. Because subjects continued KE training during phase 2, it was likely that any changes in MV, SCF, and IMF as a result of phase 1 ST should be at least maintained during phase 2 and therefore were examined for any effect on physical function. However, because single-leg training was unlikely to produce significant improvement in physical function, phase 2 ST was used to target all major muscle groups believed to be important for physical functioning.

This study had some limitations. Although the use of a 2-phase ST protocol has many advantages, as described earlier, it also has limitations for the purposes of this study. For instance, MV, SCF, and IMF were assessed at baseline and after phase 1 only. Costs, excessive radiation exposure, and contamination from other phase 2 exercises prohibited CT scanning of subjects after phase 2. Some evidence suggests that much of the initial gains in muscle strength and hypertrophy occur in the earlier stages of ST and that these gains plateau after extended training (10). Our KE 1RM data support this finding as the change in KE strength resulting from phase 1 accounts for a large percentage of the change in KE strength from phase 2. Not randomly assigning our subjects to training and control groups was also a limitation of this study. However, we have experienced a bias in attrition from randomly assigned studies using training and control groups, such that those who get assigned to the training group who would have preferred volunteering for the control group show a preferential drop-out rate from those who would prefer participating in training and vice versa. Thus, this can lead to both a higher attrition rate and a drop-out bias for 1 group compared to the other. Because it is well established that ST improves physical function (8,11–13,25,34) and the length (22 weeks) of the 2-phase protocol can lead to high attrition rates, this drop-out bias can be more problematic than the selection bias resulting from not randomly assigning to groups, given that we are not attempting to generalize our results beyond people with similar characteristics of those in the present study. Not including a balance component in the training and testing may also be a limitation of this study, given that balance may play a role in some of the physical function tests.

In conclusion, the results of this study extend the previous literature on ST and physical functioning in older adults by showing that improvements in functional tests with ST are associated with increases in KE strength and power and improvements in body composition (i.e., FFM and % fat). Furthermore, combinations of these variables still only explain a moderate portion of the variability. However, there is no evidence to support a preferential order of importance for any of the variables. Nevertheless, these data will help generate new hypotheses for further study. The use of a 2-phase protocol allowed for detailed analysis of the independent effects of ST on MV, SCF, and IMF. However, these attributes did not improve the prediction models, except in the case of IMF and chair stand time. When prescribing ST for older adults, care should be taken to design routines that emphasize improvements in strength, power, and muscle mass because changes in those appear to best predict improvements in physical function.

Practical Applications

This study along with others demonstrate that ST can improve physical function when measured using standardized ADLs, even in well-functioning older adults. Furthermore, the results suggest that improvements in specific functional tasks can be predicted on the basis of improvements in lower-body strength, lower-body power, and body composition, specifically FFM. For example, a gain of 1 kg of FFM resulted in improved physical function ranging between 0.07 and 0.20 seconds when walking or climbing stairs, whereas gaining 1 kg of fat can add nearly a second to chair stand performance. These small yet significant changes are important throughout the aging process as lean tissue is replaced by fat mass. This study also provides new information regarding functional improvements in older adults using an ST protocol designed to improve strength, power, and body composition.

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