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Power Training Improves Balance in Healthy Older Adults

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Background. Age-related decline in muscle power may be an early indicator of balance deficits and fall risk, even in nonfrail adults. This study examined the dose-dependent effect of power training on balance performance in healthy older adults.

Methods. One hundred twelve community-dwelling healthy older adults (69 ± 6 years) were randomized to 8–12 weeks of power training at 20% (LOW), 50% (MED), or 80% (HIGH) of maximal strength, or a nontraining control (CON) group. Participants trained twice weekly (five exercises; three sets of eight rapid concentric/slow eccentric repetitions) using pneumatic resistance machines. Balance, muscle performance (strength, power, endurance, contraction velocity), and body composition were measured.

Results. Power training significantly improved balance performance ($p = .006$) in participants who underwent power training compared to controls. Low intensity power training produced the greatest improvement in balance performance ($p = .048$). Average contraction velocity at low load (40% one repetition maximum [1RM]) at baseline independently predicted improvement in balance following training ($r = -.29$, $p = .004$).

Conclusions. Power training improves balance, particularly using a low load, high velocity regimen, in older adults with initial lower muscle power and slower contraction. Further studies are warranted to define the mechanisms underlying this adaptation, as well as the optimum power training intensity for a range of physiological and clinical outcomes in older adults with varying levels of health status and functional independence.

PREVENTION of functional impairment and disability as serious clinical sequelae of falls is a key objective in successful aging. Despite some success in falls prevention strategies, the magnitude of this public health problem has not been reduced. Many strategies to improve balance dysfunction, a major risk factor for falls, have included specific balance training strategies (1–5), strength training (6,7), walking (8), Tai Chi (3), and multidimensional exercises (9,10). Few interventions, however, have showed consistent positive outcomes in balance.

Muscle power (Force × Velocity of shortening) declines earlier and more precipitously with age than does strength or endurance (11). Recently, muscle power (7,12) and contraction velocity (13) have demonstrated greater influence on functional performance, particularly in low intensity tasks, than has muscle strength. Elderly fallers in the community (14) and nursing homes (15) have shown less power in lower limbs than have nonfallers, indicating that low muscle power may discriminate between these groups. We have reported that lower muscle power is an early indicator of balance deficits and fall risk, even in nonfrail adults (16). Thus deficits in muscle power represent a feasible target for falls prevention strategies in older adults.

When threats to balance (narrowed base of support, perturbation, loss of vision, or proprioception) occur, rapid responses must be engaged to maintain postural stability. With aging, slowed response initiation further reduces the possible time to produce remedial action. The velocity at which high muscular forces can be generated may be the critical determinants to prevent a fall.

Progressive high velocity resistance (power) training results in more robust adaptations in muscle power than does low velocity progressive resistance training (17). Four training studies previously examining leg power and balance performance in the same cohort have been relatively small in size (18–21). Power training in women with self-reported disability (21) and strength training in sedentary community-dwelling elderly persons (19) improved leg power and balance, without any dose-response relationship demonstrated. By contrast, despite enhancing leg power with power training in mobility-impaired older women (18) or healthy elderly persons (20), balance did not improve significantly. Small sample size may explain the lack of statistical significance in one of these studies (18).

Thus, we hypothesized that increasing muscle power by high velocity resistance training would improve balance performance in a dose-dependent manner with the highest training intensity inducing the greatest improvements in balance.

METHODS

Study Design

Ours was a randomized, controlled trial to investigate the dose-response pattern of three intensities of power training on balance performance in healthy older adults. A single assessor took all outcome measurements. Baseline testing was blinded. The study duration was, on average, 10 weeks (initially 8 weeks and later extended to 12 weeks with additional resource availability).

Study Population

Sedentary healthy older adults were recruited to the study from the Sydney metropolitan area through advertisements in senior citizen and local newspapers, distribution of flyers, and presentations to seniors groups.

Participant screening included a telephone questionnaire followed by a resting electrocardiogram and medical evaluation by the study physician. Inclusion criteria were: $\geq$60 years of age, independent community-dwelling status, and willingness to be randomized. Exclusion criteria included: current or prior participation in resistance or power training exercise ($\geq$1/week) in the past 6 months, acute or terminal illness, myocardial infarction in the past 6 months, unstable cardiovascular or metabolic disease, neuromuscular or musculoskeletal disorders severely disrupting voluntary movement, limb amputation, upper or lower extremity fracture in the past 3 months, currently symptomatic hernias or hemorrhoids, or cognitive impairment. Each participant provided written informed consent. The Central Sydney Area Health Service and The University of Sydney Human Ethics Committees approved this study.

Primary Outcome Measure: Balance

Balance was assessed on a computerized force platform, the Chattecx Dynamic Balance System (Software version 4.20; Chattecx Corp, Chattanooga Group Inc., Hixson, TN), prior to performance tests and under standard laboratory conditions in a well lit room. The system allows testing of static balance and body sway; its operation and use is described elsewhere (22). Body sway and single-leg stand are well validated and frequently used markers of balance deficit (23–25). Timed single-leg stand is a strong predictor of falls in older adults (25). Removing the visual input in this static test further challenges postural control, and we have shown it to be a more sensitive test of early impairments than dynamic balance in healthy elderly persons (16). Increased body sway, a measure of postural stability (8,26), is associated with increased fall risk (27). Dynamic posturography enables examination of sway under various sensory conditions and responses to translational and angular perturbations, thus increasing the sensitivity beyond that of static and sway tests (22).

Three trials were allowed to complete each test without losing balance (touching hand rails, taking a step, or requiring support from the assessor). If no attempt was successful, the longest time during which balance was maintained was recorded, and data from this test only were used in the analyses. The number of trials and losses of balance were recorded. To control for possible learning effects, the tests were ordered, using a computerized, random number sequence.

Balance was tested for 30 seconds under three conditions: (i) narrow bilateral stance on platform sliding forward then backward at a speed of 8.3 s/cycle in the anterior–posterior (AP) direction; (ii) narrow bilateral stance on platform tilting up and down from 0 to ±2 degrees in the AP direction; and (iii) unilateral stance of the preferred leg on still platform with eyes open (EO) and closed (EC). Stance time and maximum sway amplitude in the AP and mediolateral directions were recorded. Therefore, a total of 18 balance measures arose from the 6 tests performed: 12 dynamic measures resulted from the sliding and tilting platform and 6 static measures from the still platform.

Balance performance was examined in two ways: (i) by a balance index (BI), and (ii) by a loss of balance score. BI was derived as a summary score of overall balance by summating all AP and mediolateral sway measures and time results respectively, to simplify interpretation of relationships with the 18 balance variables.

$$\begin{aligned}\text{BI} &= \text{sum of 12 sway measures}\\ &\quad + (180 - \text{sum of 6 time measures})\end{aligned}$$

The total time was subtracted from 180 (6 tests × 30 s = maximum possible time) to remain consistent with the direction of sway values, such that a lower BI indicated better balance (less sway, longer stance time). Loss of balance score was the total number of times balance was lost during the 6 testing protocols; lower values indicate better balance performance.

Secondary Outcome Measures: Muscle Performance

Dynamic muscle strength.—Muscle strength was assessed on digital Keiser pneumatic resistance machines fitted with A400 electronics (Keiser Sports Health Equipment, Inc., Fresno, CA) using the one repetition maximum (1RM) in five bilateral exercises: horizontal leg press, knee extension, knee flexion, seated row, and seated chest press. 1RM measurement is described by de Vos and colleagues (28). Total strength was calculated by summating the 1RM values obtained in each of the exercises.

Muscle power and velocity.—After 30 minutes of rest following strength testing, peak muscle power and velocity were assessed once at 20%, 40%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, and 85% 1RM on the same five resistance machines used for strength testing. The concentric phase of each repetition was performed as rapidly as possible, and the eccentric phase over 3 seconds. All trials were verbally cued "1 . . . 2 . . . 3 . . . Go!" One trial at each load was given with 30–60 seconds of rest between loads. The Keiser A400 software calculated work and power during the concentric phase of the repetition by sampling the system pressure (force) and position at a rate of 400 times per second. Power was calculated as the average power between 5% and 95% of the concentric phase (excluding the first and last stroke to eliminate artefact). The highest mean power produced throughout the loads tested was recorded as the peak power.

Total peak power was calculated by summing the peak power values obtained in the five exercises. Velocity was the highest speed in the cylinder between 5% and 95% of the concentric phase. Average peak velocity was calculated by summing the peak velocities obtained at 20% 1RM in the five exercises and dividing by 5. Because the highest velocities were obtained at the lowest loads, average peak velocity at 40% 1RM was also calculated.

Muscle endurance.—Muscle endurance was assessed 30 minutes after power testing. Participants were instructed to perform as many consecutive repetitions as possible at a load of 90% 1RM through their full range of motion in correct form. Each repetition was performed 3 seconds concentrically and 3 seconds eccentrically, without rest between repetitions. The test was terminated if correct technique was not achieved. Average endurance was calculated by summing the repetitions achieved in the five exercises and dividing by 5.

Body composition.—Fat-free mass (FFM) was estimated using bioelectrical impedance (BIA-101; RJL Systems, Detroit, MI). All participants were measured at the same time of day after a 12-hour fast. FFM was calculated from Lukaski and colleagues (29). The coefficient of variation of triplicate measurement on the same day in the whole sample was .057 ± .1% for resistance and .155 ± .4% for reactance.

Power Training Intervention

Participants randomized to the experimental groups performed explosive resistance training at one of three intensities using training loads equivalent to 20% (LOW), 50% (MED), or 80% (HIGH) of their most recent 1RM. Participants trained twice a week for 10 weeks. The same five exercises on the Keiser machines used for testing were performed. On one day, three sets of eight repetitions were performed with 10–15 seconds between repetitions. On the second day, a 1RM test was performed, followed by two sets of eight repetitions. Resistance was increased throughout the study relative to the participant's best 1RM. Each movement was performed with rapid concentric and slow eccentric action as described in power testing. All training sessions were directly supervised by experienced exercise trainers.

Participants randomized to the control group (CON) did not undergo training or weekly strength testing. They were instructed to maintain their current level of physical activity during the study period and were offered a home-based resistance training program upon completion of final testing. All participants were monitored for changes in body pain, health status, psychological well-being, medication, and occurrence of falls with weekly questionnaires administered in person or by telephone.

Randomization

Participants were randomly allocated to one of the three training groups or to the control group. Using a computerized randomization program, an investigator unknown to study participants generated a permuted block randomization (in blocks of four) stratified by gender. After completing the baseline assessment, participants were provided with a sealed envelope containing the allocated group in accordance with the randomization sequence.

Sample Size

Sample size was estimated for change in muscle power in the high intensity versus low intensity groups of 97% versus 45% (17), with a standard deviation of 50% (an overall estimate of other resistance training studies), as we hypothesized that a change in power would lead to a proportional change in balance. Setting the power (1 − beta) at 0.8, and an alpha value of 0.05, the total sample size required was estimated to be 100 (25/group). Estimating a dropout rate of 15%, we increased the sample size to 118.

Statistical Analyses

Statistical analyses were performed using StatView, version 5.0 (SAS Institute, Cary, NC). All data were inspected visually using histograms and descriptive statistics for normality of distribution. All values are reported as mean ± standard deviation. Groups were compared using repeated-measures analysis of variance (ANOVA) and *t* tests of continuous variables and by chi-square tests for categorical data. Variables that were different between groups and potentially related to the outcome of interest, as well as the baseline value of the particular variable, were used as covariates in analysis of covariance (ANCOVA) models of change scores. Relationships between variables of interest were analyzed with simple and forward stepwise linear regression. Participants who dropped out, refused, or were ineligible for final testing were not included in the final statistical analysis. Statistical significance was accepted at $p < .05$.

Results

Recruitment, Attrition, Adverse Events, and Compliance

Recruitment and enrollment of 112 participants are detailed in Figure 1. Twelve participants (11%) dropped out of the study; four of these dropouts were intervention-related (Figure 1). The average time of dropout was 6 ± 4 weeks. Twenty adverse events (HIGH 8, MED 7, LOW 4, CON 1) were reported in 17 participants (15%). Four adverse events related to power training occurred in HIGH, and 16 were musculoskeletal problems related to strength testing; all but one (hernia) resolved with altered training regimens or medication. Compliance (number of training sessions attended divided by the number of sessions held) including the 12 dropouts, was 90 ± 19% for HIGH, 88 ± 25% for MED, 92 ± 10% for LOW, with no difference between groups ($p = .12$). Of participants randomized to 8 and 12 weeks training, 95% and 86%, respectively, completed the intervention and final testing.

Participant Characteristics

Baseline characteristics are presented in Table 1. This study cohort (mean age 69 ± 6 years) was a healthy, highly

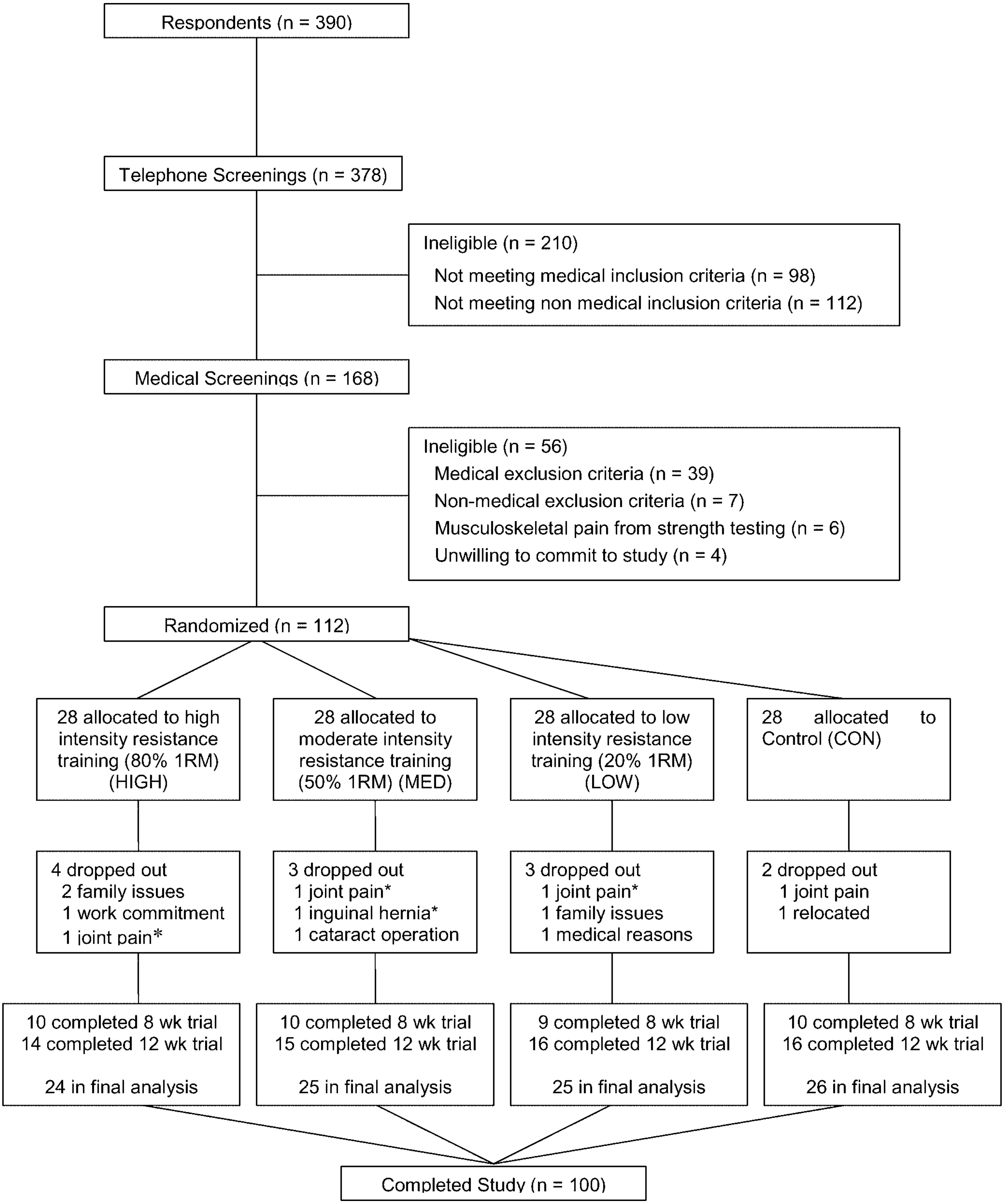

Figure 1. Flow of participants through the study. *Dropouts probably related to training or testing. Eight of the 12 dropouts were not related to the intervention. Recruitment and enrollment of participants took place from March 2002 through May 2003. Among ineligible respondents, 123 were due to nonmedical exclusions and 143 were due to medical exclusions, primarily musculoskeletal pain and unstable cardiovascular condition. Thus, 29% of the original respondents were eligible and randomized.

Table 1. Participant Characteristics

Characteristics	Total (N = 112)	HIGH (N = 28)	MED (N = 28)	LOW (N = 28)	CON (N = 28)	p
Age, y	68.5 ± 5.7	69.0 ± 6.4	68.1 ± 4.5	69.4 ± 5.8	67.6 ± 6.0	.63
Female, n (%)	68 (61)	17 (61)	17 (61)	17 (61)	17 (61)	1.0
BMI, kg/m^2	26.0 ± 3.6	26.0 ± 3.3	26.5 ± 3.9	26.2 ± 3.7	25.2 ± 3.8	.62
% Body fat*	35.1 ± 7.6	34.5 ± 6.7	35.3 ± 8.0	36.1 ± 8.4	34.3 ± 7.4	.79
No. of chronic diseases	1 (0–4)	1 (0–4)	1 (0–3)	0.5 (0–3)	1 (0–6)	.77
No. of daily medications	1 (0–7)	1 (0–7)	1 (0–7)	1 (0–6)	1 (0–6)	.95
Habitual physical activity[†]	116.1 ± 54.0	116.0 ± 50.7	120.0 ± 71.5	111.4 ± 44.3	117.0 ± 51.3	.96
Cognition[‡]	29 (27–30)	30 (27–30)	30 (27–30)	29 (28–30)	30 (28–30)	.81
Fallers, n (%)[§]	24 (21)	3 (12)	9 (32)	6 (21)	6 (21)	.28

Notes: Values of normally distributed data are presented as mean ± standard deviation (*SD*). Skewed data are presented as median (range).

Values of p were determined by chi-square for fallers, Kruskal–Wallis analysis of variance (ANOVA) for number of chronic diseases, number of regular medications, and cognition, and by factorial ANOVA for others. A p value of <.05 was accepted as statistically significant.

*Percent body fat was determined using bioelectrical impedance analysis (29).

[†] The Physical Activity Scale for the Elderly (PASE) was used to estimate habitual physical activity level during leisure time, household, and work-related activities (30).

[‡] Values given are median (range). Cognition: Mini-Mental State Examination (scale of 0–30), with scores <24 indicating cognitive impairment (31).

[§] "Fallers" refers to the percentage of participants who reported 1 or more falls in the past 12 months.

HIGH = high intensity (80% one repetition maximum [1RM]) group; MED = medium intensity (50% 1RM) group; LOW = low intensity (20% 1RM) group; CON = control group; BMI = body mass index.

functioning group with scores above Australian population norms by age on the SF-36 health-related quality-of-life questionnaire (32). There were no differences between groups in any characteristic or performance variable at baseline.

Primary Outcomes

Balance performance is presented in Table 2. BI improved significantly over time (p < .0001), and a significant Group × Time interaction (p = .006) was observed. Post hoc t testing from an ANCOVA model adjusted for baseline BI showed the best improvement in the LOW group; this improvement was significantly higher than in the HIGH (mean difference 9.71, p = .0003), MED (mean difference 8.73, p = .001), and CON (mean difference –6.51, p = .012) groups (Figure 2). Total loss-of-balance scores improved significantly over time (p = .003), where the LOW group showed the same trend as BI (p = .099).

Baseline Characteristics Predicting Balance Improvement

Baseline characteristics predictive of better balance after training in this cohort were older age (r = .22, p = .034), lower peak power/FFM (r = .20, p = .05), and lower average peak velocity at 20% (r = .27, p = .010) and 40% 1RM (r = .29, p = .004). When these predictors were entered into a forward stepwise regression model, only velocity contributed independently to the variance in better balance (r = .29, p = 0.004), explaining 9% of the variance.

Predicting Improvements in Balance with Training-Induced Changes

Improved balance was associated with reduced average muscle endurance (r = .22, p = .045) and muscle endurance/FFM (r = .22, p = .043). Improved average velocity at a load of 40% 1RM exhibited a trend towards significance (p = .065).

Secondary Outcomes (Muscle Performance)

Changes in power, strength, and endurance are summarized in Table 3 and described in detail elsewhere (28).

DISCUSSION

To our knowledge, this is the first dose-response study of power training and balance performance in elderly persons. This robust study provides the most comprehensive assessment of muscle power and balance in a large cohort of independent older adults not selected for impairments

Table 2. Balance Performance Prior to and After Power Training

	HIGH		MED		LOW		CON		Time	Group × Time
Balance Performance	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Effect p	Interaction p
BI	93.6 ± 18.3	92.6 ± 15.7	84.9 ± 13.7	82.9 ± 14.3	90.4 ± 16.6	79.6 ± 12.6	88.7 ± 9.9	84.5 ± 13.9	<.0001*	.006*
% Change		−.3 ± 9.6		−2.1 ± 10.4		−10.8 ± 12.6		−4.9 ± 10.0		
Loss of balance score	4.3 ± 1.8	4.2 ± 2.1	3.6 ± 1.3	3.5 ± 1.3	4.3 ± 1.8	3.5 ± 1.5	4.0 ± 1.2	3.6 ± 1.2	.003*	.099

Notes: Values of normally distributed data are presented as mean ± standard deviation.

Balance was measured by BI = sum of 12 sway measures + (180 − sum of six time measures), with lower scores indicating better overall balance performance. Loss of balance score was total number of times balance was lost during the six testing protocols, with lower values indicating better balance performance.

*p value of <.05 was accepted as statistically significant.

HIGH = high intensity (80% one repetition maximum [1RM]) group; MED = medium intensity (50% 1RM) group; LOW = low intensity (20% 1RM) group; CON = control group; Pre = baseline measure; Post = after power training; BI = balance index.

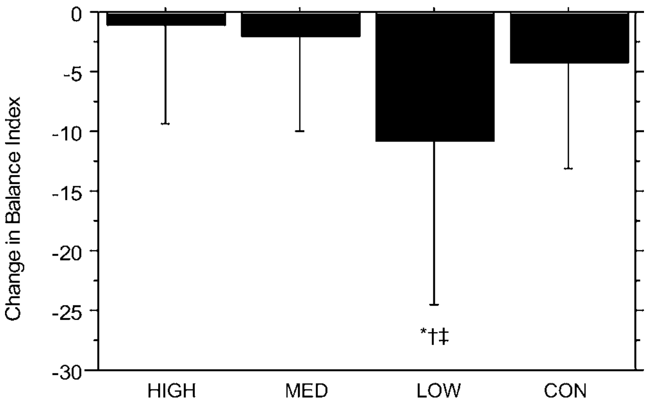

Figure 2. Change in balance index (BI) after power training. Values are presented as mean ± standard deviation. HIGH = high intensity (80% one repetition maximum [1RM]) group; MED = medium intensity (50% 1RM) group; LOW = low intensity (20% 1RM) group; CON = control group. There was a significant group effect ($p < .0001$) and Group × Time interaction ($p = .006$) for change in BI. Analysis of variance (ANOVA) model for change in BI was adjusted for baseline value. Fisher's protected-least-significant difference post hoc comparisons revealed: LOW *significantly greater than HIGH ($p = .0003$), †significantly greater than MED ($p = .001$), and ‡significantly greater than CON ($p = .012$). *$p < .05$ was accepted as statistically significant.

Table 3. Average Percent Improvement in Muscle Performance After Power Training

Muscle Characteristic	HIGH	MED	LOW	CON	*p* Value
Peak power	14 ± 8*	15 ± 9*	14 ± 7*	3 ± 6	<.0001
Strength	20 ± 7*†‡	16 ± 7*‡	13 ± 7*	4 ± 4	<.0001
Endurance	185 ± 126*†‡	103 ± 75*	82 ± 57*	26 ± 29	<.0001

Notes: Values of normally distributed data are presented as mean ± standard deviation. There were significant time effects and Group × Time interactions for average improvement in peak power, strength, and endurance. Analysis of covariance (ANCOVA) models for peak power and strength were adjusted for baseline value and fat-free mass. ANCOVA model for endurance was adjusted for baseline value and habitual physical activity. Fisher's protected-least-significant-difference post hoc comparisons revealed:

*Significantly greater than CON ($p < .004$).

†Significantly greater than MED ($p < .05$).

‡Significantly greater than LOW ($p < .05$).

A p value of <.05 was accepted as statistically significant.

HIGH = high intensity (80% one repetition maximum [1RM]) group; MED = medium intensity (50% 1RM) group; LOW = low intensity (20% 1RM) group; CON = control group.

reported to date. We found that 10 weeks of power training improves balance. Power training with low load demonstrated the greatest improvements in balance. This result was contrary to our hypothesized outcome that power training at higher loads would induce the greatest improvements in balance in this cohort due to greater improvements in the proposed proximate mediator, muscle power. Unexpectedly, power changed equally between training groups. Thus, training at low load may have optimized other adaptations necessary for the task of balancing.

We have also shown for the first time, to our knowledge, that slow contraction velocity at baseline independently contributed to improved balance performance. Age and lower power were other predictive factors, but were no longer related after velocity was accounted for. These relationships suggest that power training may be most beneficial for balance outcomes in older adults targeted for greater muscle power deficits and slow contraction velocity. Many training studies confirm that the greatest benefits are observed in those persons with the lowest physiological function. This finding needs to be confirmed in cohorts selected for low muscle power, or with greater degrees of frailty or fall risk than our group had.

We observed that power training increased average muscular strength and endurance in a dose-response manner with training intensity, yet augmented power to a similar extent in all training groups. Improved balance tended to be related to increased contraction velocity, suggesting that muscle speed may be more specific to balance tasks than is strength. We found that the HIGH group showed the greatest improvement in strength and endurance yet had the least improvement in balance. Thus increased strength and endurance were not associated with improved balance, which is in agreement with previous studies (6,33). These results highlight the complexities of developing exercise programs for clinical outcomes in older adults. On the basis of our findings, optimal improvements in strength and endurance during power training may require a high velocity and high load regime. However, optimal improvements in balance may require high velocity and low load training, whereas power itself can be achieved across a variety of loads.

Factors primarily responsible for improved balance in this cohort were not directly determined, but may be explained by enhanced neural function or force control. Horak and associates (34) hypothesize that neural control processes provide optimal strategies (an overall ''plan for action'') to counter perturbations to balance. Power training at light loads enables muscles to remain activated throughout the concentric phase of the movement, maintain the level of force output, accelerate the load throughout the full range of motion, and reduce the deceleration phase toward the end of the range (35). It is possible that power training can modify components of the neural pathway, although this possibility is yet to be tested directly. Power training could theoretically provide a means to enhance neural function by reducing response latency, effectively recruiting postural muscles, and improving interpretation of sensory information, consequently improving balance. The high rate of force development and motor-unit activation pattern characteristic of power training are principal stimuli for neural adaptations (36). Increased neural drive to agonist muscles may be achieved by greater active motor-unit recruitment and earlier and increased motor-unit firing rate (37,38). The improvements are most likely in the initial stages of activation. Increased electromyographic activity in the initial 100 ms of muscle activation has been reported following isometric power training (39). In addition, improved inter- and intramuscular coordination is achieved through better activation of synergist/agonist muscles and decreased co-contraction of antagonist muscles (38,40). Improved force control (ability to produce force steadily) with resistance training is hypothesized to occur by reduced motor-unit discharge variability (40). It is possible that balance improvements from power training may be explained, in part, by adaptations in force control, although no studies yet have measured all of these factors simultaneously to define the relationships. Such investigations are needed with power training interventions as well to understand and optimize its balance-enhancing potential.

There were limitations to this study. The control group received no placebo intervention. Because we intentionally selected a healthy cohort for this efficacy study, generalizability of these results in frail and/or institutionalized elderly persons, recurrent fallers, or those persons with chronic disease is yet to be determined. It is possible that power did not increase in a dose-dependent manner because all groups received weekly strength testing to precisely titrate the training stimulus, and this may have blurred any group differences in peak power after training or overestimated the effects of low intensity training on muscle function and balance.

Conclusion

Power training, particularly at low load, significantly improves balance in a healthy community-dwelling cohort. Power training may provide an efficient way to simultaneously target balance, muscle function, sarcopenia, and health outcomes related to these physiological domains. Optimal and simultaneous enhancement of these factors may require more than one intensity of power training if our results are confirmed in future studies. Further research to establish whether enhanced neural processing and activation or other factors such as force control may explain the observed improvements in balance performance is warranted.

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