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Strength Versus Muscle Power-Specific Resistance Training in Community-Dwelling Older Adults

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Background. Loss of muscle power due to normal aging has greater functional impact than loss of strength alone. The present study compared two resistance training programs, one aimed at enhancing muscle power and one at increasing muscle strength, on muscle function and functional performance in older adults.

Methods. Sixty-seven healthy, independent older adults (65–84 years) were randomized to a high-velocity varied resistance (HV), constant resistance (ST), or nontraining control (CO) group. Participants trained twice weekly for 24 weeks using six exercises. Dynamic and isometric muscle strength, muscle power, movement velocity, muscle endurance, and a battery of functional performance tasks were assessed. Secondary outcomes included body composition, quality of life, and balance confidence.

Results. Muscle strength increased significantly ($p < .001$) and similarly in the training groups compared to controls (HV, 51.0 ± 9.0%; ST, 48.3 ± 6.8%; CO, 1.2 ± 5.1%). Peak muscle power also increased with training ($p < .05$), with no difference between training groups. The change in peak power was 50.5 ± 4.1%, 33.8 ± 3.8%, and –2.5 ± 3.9% in the HV, ST, and CO groups, respectively. Training also improved selected functional performance tasks in the HV and ST groups compared to controls ($p < .05$), and the HV group reported improved quality of life ($p = .018$).

Conclusion. Muscle power and muscle strength improved similarly using either resistance training protocol, and these changes were accompanied by improvements in several functional performance tasks. However, improvements in the HV group occurred with less total work performed per training session.

***Key Words*:** Resistance training—Muscle power—Movement velocity—Functional performance—Muscle strength.

A decrease in muscle mass characterizes normal aging and contributes to a decrease in muscle performance, frailty, and loss of independence (1). Resistance training has been reliably shown to be a safe and effective method for strength development in elderly persons as well as being an important contributor to improving physical function and maintaining independence (1,2). Recently, Foldvari and colleagues (3) reported that muscle power may be of greater importance than muscle strength for tasks such as rising from a chair and climbing stairs. In addition, maintaining an adequate level of muscle power could aid in the prevention of falls and fractures in older adults (4). Although it has been reported that adults in their 70s retain 50% of the strength and only 25% of the power of their younger counterparts (5), only a paucity of research has examined muscle power training in older adults.

Constant resistance and moderate velocity training protocols have resulted in significant enhancement of muscle strength in older adults (1,2). Although this mode of training has also been used to increase muscle power (6,7), these changes most often occur through increased force capacity in the force–velocity relationship (8). Importantly, following strength training, muscle power changes at the high-resistance end of the force–velocity spectrum do not transfer to lower forces that are associated with more rapid movements (8). Consequently, the effect of strength training on the muscle power requirements for tasks of daily living, which occur at a range of velocities and resistances, is uncertain.

Recently, the use of optimized training loads (low, moderate, and high resistances) in weight-training interventions for older adults has resulted in increased rates of force production and muscle power across a range of resistances (9,10). Previously used among younger athletes to increase muscle power, training protocols prescribing varied resistances (30%–70% one repetition maximum [1RM]) and maximal velocities are suggested to selectively target Type II muscle fibers (11). Due to the preferential loss of Type II fibers and the associated decrease in movement velocity with aging, incorporating explosive movements may be beneficial in the training regimens of older persons (4). Furthermore, programs that will increase both the muscle force and movement velocity should be prioritized due to the significant advantages during tasks such as rising from a chair or stair climbing (4). However, a direct comparison of the benefits of varied-resistance muscle power training to strength training in older persons on muscle and physical function has not been undertaken.

Therefore, the purpose of the study was to compare strength training to a high-velocity varied-resistance muscle power program in older adults to assess which has the greater benefit on muscle function and physical performance. We hypothesized that muscle power training would have greater impact on power-based functional tasks, muscle power, and movement velocity than would strength training.

Methods

Participants

Independently living, community-dwelling older adults aged 65–84 years were recruited from the Brisbane city area by newspaper advertisement. When potential participants (n = 139) made contact, a short telephone interview took place to establish their eligibility for the study. The exclusion criteria included (i) acute or terminal illness, (ii) unstable or ongoing cardiovascular and/or respiratory disorder, (iii) neurological or musculoskeletal disease or impairment, (iv) resistance training experience within the previous 12 months, and (v) the inability to commit to a period of time equivalent to the duration of the study. Following the telephone interview, information packages detailing the study and requesting that potential participants obtain their physicians' approval for participation were sent. Having received this packet, participants were invited to attend two familiarization sessions, during which exercise techniques were demonstrated and practiced, then baseline testing was undertaken. Following baseline assessment, 67 participants were randomized to either a high-velocity training (HV = 23: 11 men, 12 women), strength training (ST = 22: 10 men, 12 women) or nontraining control (CO = 22: 10 men, 12 women) group for 24 weeks. The study was approved by the University of Queensland Medical Research Ethics Committee, and all participants provided written informed consent.

Training Protocol and Study Design

Twice-weekly training was undertaken using Extek resistance equipment (Extek Pty. Ltd., Brisbane, Australia). Training consisted of a 10-minute warm-up that included stretching, six resistance training exercises (chest press, supported row, biceps curl, leg press, prone leg curl, and leg extension) and concluded with a cool-down of abdominal crunches and the prone superman exercise to target core stabilizers. All training sessions lasted approximately 1 hour, were separated by a minimum of 2 days and were performed under the direct supervision of an exercise instructor to ensure safety and the maintenance of the exercise protocols.

The intervention was divided into a conditioning (2 weeks) and training phase. Following conditioning, participants undertook a 1RM testing session, with the 1RM value used to calculate the individual's resistance at the beginning of the training phase. Due to the strenuous nature of this event, it was considered a training session and consequently participants completed 43 sessions using either the HV or the ST protocol in the remaining 22 weeks.

Conditioning training protocol.—The conditioning phase consisted of the first four training sessions to prepare participants for the training program (8). Participants completed three sets of each exercise performing eight repetitions at 65% of their baseline 1RM for the first two sessions, and 70% of their 1RM for the third and fourth sessions, with a ~1-minute rest between sets. Concentric and eccentric movements were performed at a rate of ~3 seconds.

Strength training protocol.—Following conditioning, the ST group continued training using three sets of eight repetitions at 75% 1RM. The movement speed of 3 seconds per concentric and eccentric phase was maintained for the duration of the study.

High-velocity training protocol.—The HV protocol was based on previous work conducted in our laboratory (9), following the proposal that optimal upper- and lower-body muscle power is achieved using maximal movement velocity at 40%–60% and 50%–75% 1RM, respectively (12). Specifically, participants were instructed to produce the concentric portion of each repetition as rapidly as possible, then return through the eccentric phase at a slow and controlled pace (~3 seconds). In comparison to the ST group, the HV group performed ~20% less work per exercise, using two lighter sets in addition to one high-intensity set as follows:

Set 1: 8 reps @ 45% 1RM
Set 2: 8 reps @ 60% 1RM
Set 3: ≥8 reps @ 75% 1RM

To ensure that the program was progressive for both exercise groups, the resistance was increased when the number of repetitions that a participant could complete was >8 in their final set, as described previously (6). Briefly, when participants could complete 10 or 11 repetitions their 1RM was increased by 5%, and when they could complete ≥12 repetitions their 1RM was increased by 10%. Resistance adjustments were undertaken following the final session each week.

Measures

Data were collected for all variables at baseline and week 24. In addition, to examine short-term training effects, muscle strength, muscle endurance, and functional performance were assessed at week 8. During assessment, the order of testing within each battery, the test administrator, and the time of day used for collection remained constant. All tests of muscle function were conducted on the same pin-weight equipment used by participants during training.

Muscle Function

Dynamic muscle strength and muscle endurance.—Dynamic concentric muscle strength for all exercises was measured using the 1RM method, which we have described previously (13). Briefly, an individual's 1RM is the maximum weight that can be moved through the full range of motion once with correct technique. To avoid muscle fatigue, weights were set so that the 1RM lift was achieved within 3–5 attempts (14). The coefficient of variation (CV) for repeated 1RM measures in our laboratory ranged from 2.5% to 8.8%.

Muscle endurance for the leg press and chest press exercise was determined from the maximum number of repetitions performed at 70% 1RM (15). The CV values for repeated chest press and leg press endurance were 6.4% and 4.4%, respectively.

Isometric muscle strength.—Isometric leg extension and biceps curl strength data were calculated from S-Type load cells (Celtron Technologies, Covina, CA) collected during a maximal contraction at a predetermined angle. Data were sampled through HMS-9401 load cell amplifiers (HMS Technologies, University of Queensland, Australia) and collected through the DATAQ instruments computer program (version 2.46; DATAQ Instruments Inc., Akron, OH). For leg extension, the machine arm was set at 135°, where full knee extension is 180°, and the machine arm for biceps curl was at 90° (16). Participants were given a ''go'' command and instructed to undertake the contraction explosively and to maintain maximal torque for 3 seconds. Three attempts were carried out with each maximal effort separated by 30 seconds.

For quantitative analysis, electronic data were converted to an ASCII format and forwarded to the Spike2 program (Cambridge Electronic Design Limited, Cambridge, U.K.). Mean and maximal isometric torque data were examined from the onset of force (time point 0 ms) to 500 ms, and from 500 ms to 1500 ms, to ensure the maximal peak torque phase of the contraction was incorporated (17). Only data related to the movement in which the maximal torque occurred were retained for statistical analysis. The CV values for mean and maximal biceps curl and leg extension isometric muscle strength in our laboratory ranged from 5.3% to 13.8%.

Muscle power and movement velocity.—Peak and average muscle power and movement velocity from five exercises (chest press, biceps curl, leg press, leg extension, leg curl) were calculated from measures of force (S-type load cells; Celtron Technologies), excursion (22-mm conductive plastic potentiometer; Vishay Spectrol, Munich, Germany), and duration of movement (time) (18). Data were sampled through an HMS-9401 load cell and HMS-9322a GP amplifiers (HMS Technologies) and collected through the DATAQ instruments computer program (Version 2.46; DATAQ Instruments). For conversion and movement analysis, all electronic data were forwarded to the LabView 7 Express program (National Instruments Corporation, Austin, TX). Subsequent to movement identification, data related to the biceps curl, leg extension, and leg curl, in which a varied radius cam length needed to be considered, were forwarded to Excel (Microsoft Office Excel 2003; Seattle, WA) for conversion. After all force and velocity data were finalized, files were forwarded to MatLab (The Mathworks, Inc., Natick, MA) for the calculation of power (force × velocity) and variables of interest.

Data were collected for all exercises at 45%, 60%, and 75% 1RM, and the mean of the three resistances was calculated for analysis. Prior to testing, participants were informed of the importance of the rate of movement as a component of muscle power and were encouraged to move against each resistance as rapidly as possible. All participants were given three attempts at each resistance, and repetitions were separated by 30 seconds. Due to the contribution of the biceps brachii to the acceleration phase of the supported row movement, the exercise was deemed an invalid measure of upper-back power and not included. The CV values for peak and average muscle power ranged from 2.0% to 8.2% and for maximal and average movement velocity from 1.6% to 8.3%.

Functional Performance

All participants undertook a battery of eight physical performance tests, with tests pre-scripted to ensure that participants received identical instructions. These tests were the floor rise to standing; stair climb; usual, fast, and backwards 6-m walk; repeated chair rise to standing (5 times); 400-m walk; and the functional reach test to measure static balance. All tests have been described in detail previously (9,19). The best of three trials was used in analysis, with an approximately 2-minute rest between trials, except for the 400-m walk, for which only one trial was performed. Participants were instructed to move as fast as they could safely manage in each of the tests, except for the usual 6-m walk and functional reach. The CV values for functional performance tasks in this study ranged from 2.0% to 7.5%.

Body Composition and Bone Mineral Density

Height in centimeters (cm) and body mass in grams (g) were obtained using a stadiometer and electronic scale, respectively. Body mass index (BMI) was calculated as weight in kilograms divided by height squared in meters. Whole body lean mass, fat mass, percent body fat, and total body and hip bone mineral density (BMD, g/cm^2) were determined by dual x-ray absorptiometry (DXA; Hologic Discovery W; Hologic Inc., MA). The CV for repeated body composition measures are $<$1.0%.

Lifestyle Questionnaires

Physical activity was assessed through the use of the Physical Activity Scale for the Elderly (20), which assessed the amount of activity a participant undertook in the week prior to its completion. The Activities-specific, Balance Confidence Scale was used to assess falls self-efficacy (21), and the University of Queensland Quality of Life questionnaire was administered to assess health-related quality of life. Finally, participants completed a health history questionnaire at baseline to record past and present conditions and medications. All questionnaires were self-administered. Participants were issued a package of questionnaires at the designated periods and were requested to return them within 1 week. In addition, the Medical Outcomes Study Short Form was administered at baseline to assess general health (22).

Statistical Analyses

Data were analyzed using the SPSS (SPSS 13.0; Chicago, IL) statistical software package. Analysis of variance (ANOVA) was used to determine if any differences existed among groups at baseline. For variables with three time points (baseline, week 8, and week 24) a two-way (Group × Time) repeated-measures analysis of covariance (ANCOVA) adjusted for sex was used to examine change among groups, and for variables with two time points ANCOVA adjusted for baseline values and sex. Repeated-measures ANOVA and paired t tests were used to investigate within-group changes. Where appropriate, the Bonferroni post hoc procedure was used to locate the source of differences. Percent change was calculated on individual data as (final – baseline)/ baseline $\times$ 100, with the mean of the group change reported. All tests were two-tailed, and an α level of .05 was required for significance. All values are expressed as the mean $\pm$ standard error.

Results

Participants

Eight participants withdrew from the study by week 8 and a further 6 by week 24, resulting in 53 participants completing the study (HV = 19: 7 men, 12 women; ST = 19: 10 men, 9 women; CO = 15: 6 men, 9 women). Those who dropped out were not distinguished from those who completed the study. Reasons for dropping out included medical conditions and family problems; however, no participants indicated that the training protocol or intensity was the reason for leaving the study. Baseline characteristics for those who completed the study are presented in Table 1. At baseline, there was no difference among groups for any measured variable except for maximal and average leg press and maximal chest press movement velocity, where the HV group was slower than the ST group (12.3%, 14.1%, and 17.9%, respectively) ($p < .05$), and also slower than CO for average chest press velocity (14.3%) ($p < .05$). In addition, due to variation in the number of men and women within each group, analyses were adjusted for sex.

Following training, there was a significant increase in lean mass for all groups (HV: 1.2 $\pm$ 0.2, ST: 1.4 $\pm$ 0.3, CO: 0.6 $\pm$ 0.3 kg), and a decrease in fat mass (HV: –0.6 $\pm$ 0.3, ST: –0.8 $\pm$ 0.4, CO: 0.1 $\pm$ 0.3 kg) and percent fat (HV: –1.3 $\pm$ 0.2, ST: –1.3 $\pm$ 0.3, CO: 0.2 $\pm$ 0.2%) for the training groups ($p < .05$). However, there was no significant effect on body weight, and there was no effect of the exercise program on BMD. In addition, there was no change in self-assessed physical activity or balance confidence; however, the HV group had a significant, though modest, increase in quality of life from 61.1 $\pm$ 1.7 to 63.9 $\pm$ 1.7 ($p = .018$).

Muscle Function

Dynamic muscle strength and muscle endurance.—Following training, and for each muscle strength exercise, there was a significant effect for time ($p < .001$) and Group $\times$ Time interaction ($p < .001$), with the HV and ST groups increasing their maximal strength for each exercise (Figure 1). There was no difference between exercise groups for any measure of muscle strength, and there was no change in the control group. The average change in total body muscle strength (across six exercises) was 51.0 $\pm$ 9.0%, 48.3 $\pm$ 6.8%, and 1.2 $\pm$ 5.1% for the HV, ST, and CO groups, respectively. There was no difference among groups for chest press or leg press muscle endurance following either short-term or long-term training.

Isometric muscle strength.—Maximal and mean isometric leg extension strength from 500 ms to 1500 ms postonset of force increased in the HV group compared to controls ($p < .05$) (Table 2). In contrast, training significantly increased maximal isometric bicep curl strength, 500 to 1500 ms, in the ST group when compared to controls ($p = .037$). No differences between exercise groups emerged following training. Overall, maximal isometric strength increased 29.7 $\pm$ 6.9%, 23.8 $\pm$ 5.5%, and 1.5 $\pm$ 4.1% in the HV, ST, and CO group, respectively.

Muscle Power and Movement Velocity

Absolute values for peak and average muscle power are presented in Table 3. Peak power increased significantly in exercise groups compared to controls ($p < .05$) for all exercises except the chest press, where only the HV group displayed greater power than CO ($p < .05$). Average change in peak power was 50.5 $\pm$ 4.1%, 33.8 $\pm$ 3.8%, and –2.5 $\pm$ 3.9% for the HV, ST, and CO groups, respectively. Average power was also significantly greater in the HV and ST groups than in the CO group following training ($p < .05$). No differences were observed between training groups. Within-group analysis revealed significant improvements in peak and average muscle power for the training groups ($p \leq .001$), whereas the control group had an increase in average leg curl power ($p = .034$) and a decrease in peak biceps curl power ($p = .003$).

Following training, only maximal movement velocity for the chest press displayed a significant difference among groups ($p = .005$) with the ST group having slower movement velocity than the HV and CO groups. Within-group analysis revealed a significant decrease in maximal chest press and leg extension, and increases in average chest press and leg curl movement velocity of the ST group ($p < .05$). In contrast, the HV group experienced a significant increase in maximal and average chest press, and average biceps curl and leg press velocity of moment ($p < .05$). In addition, all groups displayed a significant decrease in maximal leg curl movement velocity ($p < .05$).

Functional Performance

For the stair climb, 6 m fast walk, chair rise, and functional reach task there was a significant Group $\times$ Time interaction ($p < .05$) (Table 4). For the repeated chair rise and stair-climbing task, the HV group performed significantly better than controls at week 8 ($p = .004$), and both training groups performed better than CO for the 6 m fast walk and the chair-rise task at week 24 ($p \leq .001$). In addition, at week 8 the ST group performed better than controls for the 6 m fast walk, and at weeks 8 and 24 for the functional reach task ($p < .05$). No differences were observed between training groups for any measure of functional performance.

Discussion

This study comprehensively compared the effects of a strength training program to that of a power-specific resistance training protocol on muscle function and functional performance in community-dwelling older adults. In

Table 1. Participant Characteristics, Mean and Maximal (Max.) Isometric Strength, and Peak (P) and Average (A) Muscle Power at Baseline

Variable	HV ($N = 19$)	ST ($N = 19$)	CO ($N = 15$)	p
Age, y	71.2 ± 1.3	69.6 ± 1.1	69.3 ± 1.0	.497
Height, cm	163.3 ± 1.7	167.6 ± 1.8	167.9 ± 2.1	.155
Weight, kg	71.7 ± 2.0	76.5 ± 2.5	71.9 ± 2.9	.373
Body mass index, kg/m^2	26.9 ± 1.0	27.3 ± 0.8	25.5 ± 1.0	.418
Fat mass, kg	25.1 ± 1.8	24.4 ± 1.7	22.7 ± 2.0	.656
Lean mass, kg	43.4 ± 2.0	48.6 ± 2.2	46.2 ± 2.4	.233
% Body fat	35.4 ± 1.8	32.4 ± 2.0	31.8 ± 2.3	.393
Bone mineral density, g/cm^2				
Whole body	1.11 ± 0.04	1.10 ± 0.03	1.05 ± 0.03	.489
Total hip	0.91 ± 0.03	0.90 ± 0.03	0.85 ± 0.03	.330
Quality of life*	61.1 ± 1.7	59.3 ± 2.0	62.5 ± 2.7	.578
Balance confidence*	147.1 ± 4.1	143.2 ± 3.5	144.9 ± 3.8	.766
Self-rated physical ability*	3.8 ± 0.2	3.7 ± 0.2	3.9 ± 0.4	.802
Self-rated general health*	75.3 ± 3.9	74.9 ± 2.2	77.7 ± 3.2	.806
Physical activity	165.8 ± 15.4	145.1 ± 10.4	165.2 ± 20.9	.551
Number of medications	1.2 ± 0.2	1.4 ± 0.4	1.7 ± 0.4	.612
Falls†	21.1	36.8	26.7	.383
Isometric strength				
Biceps curl				
Mean 0–500 ms	6.4 ± 0.9	6.7 ± 0.6	7.5 ± 1.0	.740
Mean 500–1500 ms	24.3 ± 1.9	26.0 ± 1.3	27.3 ± 2.6	.655
Max 0–500 ms	20.4 ± 2.3	23.1 ± 1.3	24.5 ± 2.5	.499
Max 500–1500 ms	25.6 ± 1.8	27.2 ± 1.4	28.3 ± 2.7	.703
Leg extension				
Mean 0–500 ms	11.5 ± 1.9	23.0 ± 3.2	25.2 ± 5.0	.052
Mean 500–1500 ms	84.6 ± 7.8	105.8 ± 6.8	108.8 ± 14.7	.222
Max 0–500 ms	50.6 ± 7.1	80.7 ± 9.8	90.4 ± 16.4	.058
Max 500–1500 ms	103.6 ± 8.4	125.4 ± 6.3	122.7 ± 15.1	.285
Muscle power				
Chest press				
P	159.4 ± 22.7	239.3 ± 34.1	234.6 ± 43.2	.184
A	68.3 ± 9.7	86.7 ± 10.4	92.5 ± 16.5	.359
Biceps curl‡				
P	91.8 ± 13.2	142.9 ± 18.5	120.3 ± 23.0	.170
A	44.6 ± 6.7	66.1 ± 7.5	54.6 ± 10.0	.206
Leg press				
P	268.2 ± 25.1	330.0 ± 31.0	292.0 ± 49.1	.501
A	98.1 ± 7.7	115.7 ± 9.3	99.5 ± 15.8	.543
Leg curl	125.4 ± 13.4	166.2 ± 17.3	147.5 ± 23.6	.314
P				
A	26.8 ± 6.5	18.3 ± 8.8	21.5 ± 8.6	.724
Leg extension				
P	239.2 ± 24.4	317.4 ± 34.9	296.7 ± 51.6	.303
A	105.0 ± 9.2	132.1 ± 13.0	131.7 ± 21.6	.332

Notes: Values are mean ± standard error.
*Possible range: quality of life; 5–80; balance confidence, 16–160; self-rated physical ability, 1–5; self-rated general health, 0–100.
†Percent who fell in the year previous to baseline assessment.
‡ST ($n = 18$).
HV = high-velocity varied resistance; ST = strength training; CO = control.

contrast to our hypothesis, the results indicate that both programs significantly and similarly enhanced multiple components of muscle function and functional performance. Importantly, these benefits occurred for the HV group using a reduced total workload per exercise session. These findings support the efficacy of using high-velocity varied resistance training protocols in older adults as a means to enhance physical function.

Muscle Power and Movement Velocity

The present study supports previous research that has reported increased muscle power following resistance

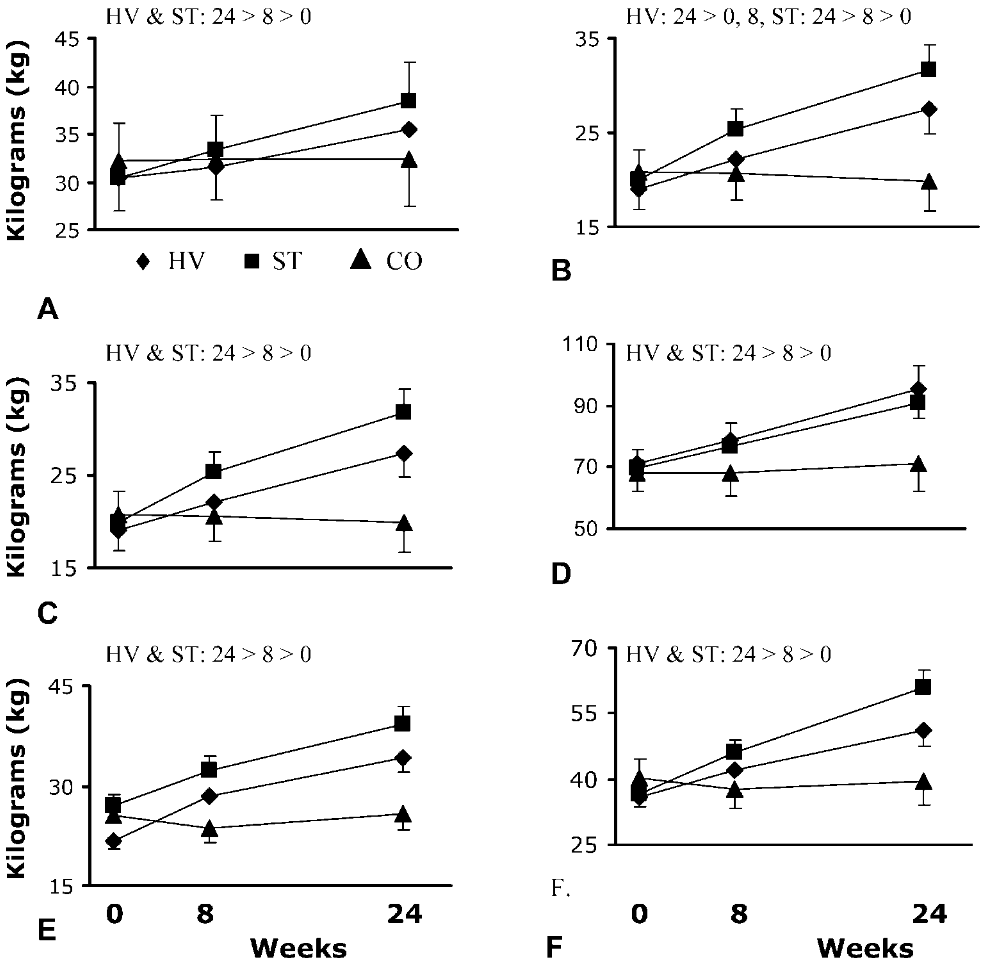

Figure 1. Short- and long-term changes in muscle strength for groups of older adults undertaking high-velocity varied resistance training (HV) or strength training (ST) or nontraining controls (CO) for bench press (**A**), supported row (**B**), biceps curl (**C**), leg press (**D**), leg curls (**E**), and leg extension (**F**). Within-group comparisons are presented in each exercise, $p < .05$.

training. However, it is the first to compare power-specific training at varied resistances to strength training. Although no statistical differences between training groups emerged, relative percent change data indicate that the HV group had notably larger increases in peak muscle power than their ST counterparts. The present study extends previous work from our laboratory (9) on lower-body muscle power by demonstrating that both upper-body and lower-body muscle power are enhanced following an extended period of training. Recently, de Vos and colleagues (10) investigated the optimal training load (20% [G20], 50% [G50], or 80% [G80] 1RM) to increase muscle power in

Table 2. Maximal (Max.) and Mean Isometric Muscle Strength (Nm) in Older Adults Following 24 Weeks of Resistance Training Adjusted for Baseline Values and Sex

Variable	Range	HV (N = 19)	ST (N = 19)	CO (N = 15)	p Value*
Biceps curl	Mean 0–500 ms	7.9 ± 0.6†	6.2 ± 0.6	7.3 ± 0.7	.185
	Mean 500–1500 ms	28.4 ± 1.3†	30.5 ± 1.3†	26.5± 1.5	.145
	Max. 0–500 ms	24.7 ± 1.8	23.0 ± 1.7	23.8 ± 2.1	.776
	Max. 500–1500 ms	30.5 ± 1.3‡	32.9 ± 1.3‡	27.6 ± 1.5	.037
Leg extension	Mean 0–500 ms	31.1 ± 3.4‡	24.5 ± 3.2	23.4 ± 3.8	.289
	Mean 500–1500 ms	129.9 ± 6.3‡	119.2 ± 6.2†	103.7 ± 7.3	.035
	Max. 0–500 ms	113.7 ± 9.3‡	94.2 ± 9.0	83.4 ± 10.7	.113
	Max. 500–1500 ms	140.3 ± 6.2‡	132.4 ± 6.1	116.3 ± 7.0	.045

Notes: Values shown are adjusted mean ± standard error.

*Between groups following training adjusted for baseline and sex (analysis of covariance).

†Significant within-group difference from baseline ($p < .05$).

‡Significant within-group difference from baseline ($p \leq .001$).

HV = high-velocity varied resistance; ST = strength training; CO = control.

Table 3. Peak (P) and Average (A) Muscle Power (W) in Older Adults Following 24 Weeks of Resistance Training Adjusted for Baseline Values and Sex

Variable	HV ($N = 19$)	ST ($N = 19$)	CO ($N = 15$)	p Value*	Comparison†
Chest press					
P	283.6 ± 11.3	248.7 ± 10.9	232.1 ± 12.7	.014	HV > CO
A	112.5 ± 3.7	102.9 ± 3.7	87.8 ± 4.3	<.001	HV, ST > CO
Biceps curl‡					
P	155.9 ± 9.0	160.3 ± 9.1	98.2 ± 9.8	<.001	HV, ST > CO
A	81.9 ± 4.7	80.4 ± 4.8	48.6 ± 5.1	<.001	HV, ST > CO
Leg press					
P	423.4 ± 15.9	403.9 ± 15.9	253.8 ± 17.8	<.001	HV, ST > CO
A	148.9 ± 8.0	153.2 ± 8.1	91.5 ± 9.0	<.001	HV, ST > CO
Leg curl					
P	207.5 ± 9.8	204.4 ± 9.7	150.3 ± 10.8	<.001	HV, ST > CO
A	53.1 ± 4.6	53.3 ± 4.6	42.3 ± 5.1	.208	
Leg extension					
P	370.1 ± 17.2	372.1 ± 17.0	292.0 ± 19.2	.005	HV, ST > CO
A	170.1 ± 9.7	174.4 ± 9.6	133.4 ± 10.9	.015	HV, ST > CO

Notes: Values shown are adjusted mean ± standard error.
*Analysis of covariance adjusted for baseline values and sex.
†Bonferroni post hoc between-group multiple comparisons.
‡ST ($n = 18$).
HV = high-velocity varied resistance training; ST = strength training; CO = control.

older adults. Following training, absolute total-body peak power was greater in G50 than G20, with no other differences observed. However, it is unclear if the increases were force or movement velocity dependent. Moreover, in contrast to the testing protocol used by de Vos and colleagues (10), we removed the influence of regular 1RM assessment so specific power or strength training benefits could emerge.

Table 4. Functional Performance at Baseline and Following 8 and 24 Weeks of Resistance Training in Older Adults, Adjusted for Sex

					p Value*		
Variable	Group	Baseline (0)	Week 8	Week 24	Time	Group × Time	Comparison†
Floor rise to standing (s)‡	HV	3.49 ± 0.29	3.58 ± 0.32	3.54 ± 0.29	.023	.325	
	ST	3.77 ± 0.29	3.81 ± 0.31	3.69 ± 0.28			
	CO	3.68 ± 0.38	3.96 ± 0.38	3.98 ± 0.37			8, 24 > 0
Stair climb (s)	HV	4.89 ± 0.17	4.52 ± 0.19	4.57 ± 0.21	.687	.042	0 > 8
	ST	4.81 ± 0.17	4.64 ± 0.19	4.70 ± 0.21			
	CO	4.85 ± 0.20	5.10 ± 0.21	5.00 ± 0.23			
Usual 6 m walk (s)	HV	3.93 ± 0.08	3.78 ± 0.11	4.04 ± 0.08	.435	.064	24 > 8
	ST	3.95 ± 0.08	3.88 ± 0.11	3.81 ± 0.08			
	CO	3.86 ± 0.09	3.95 ± 0.13	4.09 ± 0.09			
Fast 6 m walk (s)	HV	3.15 ± 0.08	2.94 ± 0.08	3.02 ± 0.07	.383	.005	0 > 8
	ST	3.13 ± 0.08	2.91 ± 0.08	2.93 ± 0.07			0 > 8, 24
	CO	3.02 ± 0.08	3.13 ± 0.09	3.19 ± 0.07			
Backward 6 m walk (s)	HV	18.91 ± 1.13	17.66 ± 1.29	15.97 ± 0.97	.498	.284	
	ST	17.81 ± 1.14	16.42 ± 1.29	15.83 ± 0.99			0 > 8, 24
	CO	19.12 ± 1.28	17.75 ± 1.45	18.51 ± 1.11			
Chair rise (s)	HV	11.77 ± 0.44	10.27 ± 0.41	10.26 ± 0.38	.598	.002	0 > 8, 24
	ST	12.29 ± 0.44	11.38 ± 0.41	10.99 ± 0.39			0 > 24
	CO	12.10 ± 0.49	12.18 ± 0.46	12.56 ± 0.43			
Functional reach (cm)	HV	31.17 ± 1.11	33.35 ± 1.06	33.86 ± 1.11	.927	.017	24 > 0
	ST	29.24 ± 1.11	33.82 ± 1.06	33.93 ± 1.11			8, 24 > 0
	CO	31.89 ± 1.25	30.51 ± 1.19	30.81 ± 1.25			
400 m walk (s)	HV	256.15 ± 4.34	247.57 ± 5.89	236.74 ± 5.56	.513	.100	0, 8 > 24
	ST	245.39 ± 4.35	243.48 ± 5.91	237.34 ± 5.58			
	CO	247.91 ± 4.87	253.79 ± 6.61	244.94 ± 6.24			

Notes: Values shown are adjusted mean ± standard error.
*Analysis of covariance adjusted for sex.
†Within-group multiple comparisons for weeks 0, 8, and 24, $p < .05$.
‡HV ($n = 18$).
HV = high-velocity varied resistance training ($n = 19$); ST = strength training ($n = 19$); CO = controls ($n = 15$).

Although a decrease in speed of contraction has been reported as the critical determinant in power loss with aging (23), and research involving younger participants show enhanced velocity of contraction with training (24,25), we found only modest changes in movement speed post-intervention. Related to muscle fiber composition, motor unit discharge, and firing frequencies, studies to date indicate that older adults retain the ability to increase movement velocity (17,26); however, this has only been reported following interventions addressing rate of force development during maximal isometric contraction (27,28). Even though an increase in force production, and subsequently muscle power, was observed for the ST group, their decrease in movement velocity suggests that the high-velocity training regimen may have an important impact on maintained contraction speed in older adults.

Dynamic and Isometric Muscle Strength

In general, significantly greater strength gains are reported following high-intensity multiple set training than following low-intensity or moderate-intensity training (29,30), or single-set high-intensity training (31,32). In the present study, significant dynamic muscle strength gains, comparable to those of a multiple high-intensity set regimen, was achieved in older adults using a single set of high-intensity work with additional sets at a reduced load.

Furthermore, and in contrast to the ST group, the HV group experienced important increases in isometric leg extension and biceps curl strength using a reduced workload per exercise session. Although similar increases in isometric torque have been reported previously following explosive resistance training (27,28), the limited change experienced by the ST group was unexpected, particularly given the similar changes experienced for muscle power and dynamic muscle strength (33). Importantly, the HV group experienced significant increases in the initial 500 ms of the moments for all measures except maximal biceps curl. These data suggest that high-velocity explosive training may have an important impact on the neural output of the muscle that has transferred to isometric strength and rate of torque development (27,28).

Functional Performance

The present study supports our previous work showing that high-velocity varied resistance training is an effective means of increasing functional ability in previously untrained older adults (9,19). Furthermore, our study also shows that improvement in power-orientated functional tasks are not exclusively related to explosive training, as the ST group also improved their chair-rise performance following training. Therefore, it appears that, although high-velocity training is an effective means of increasing short- and long-term functional ability, the changes are similar to those obtained with strength training.

Secondary Outcomes

Both exercise regimens resulted in similar improvement in body composition comparable to those previously reported in older adults undertaking resistance exercise (34,35). The modest change in lean mass indicates the important role for nonhypertrophy-related factors for enhancement of muscle strength and power. Training participants also experienced a decrease in fat mass but no change in BMD. However, given the time course of bone remodeling, it is unlikely that 24 weeks of training was sufficient to detect change (35). In addition, a modest increase was observed in quality of life for the HV group. Although previous research indicates little or no change in self-assessed quality of life following training (36), it is unclear why similar improvements were not detected in the ST group given the similar improvements in physical function and the social interactions experienced during the intervention.

Limitations

Some potential limitations of the study are worthy of comment. The exercise groups undertook differing total workloads per session, which is not uncommon when comparing different exercise regimens. Had groups performed an equal volume of work, differences may have emerged. In addition, participants in the study were high-functioning and independently living, and may not reflect all older adults, in particular frail and institutionalized elderly persons. Therefore, care must be taken when applying these results to all groups of older adults.

Summary

Strength and high-velocity resistance training in healthy, well-functioning older adults significantly and similarly improved muscle power and muscle strength. In addition, changes in muscle function were accompanied by the enhancement of selected functional tasks. Moreover, the changes experienced following high-velocity, varied resistance training occurred with less total work performed per exercise session. These outcomes have important implications for the future design of training programs to safely and effectively enhance physical function in older persons.

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References

1. Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ. High-intensity strength training in nonagenarians. Effects on skeletal muscle. *JAMA*. 1990;263:3029–3034.
2. Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG, Evans WJ. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol*. 1988;64:1038–1044.
3. Foldvari M, Clark M, Laviolette LC, et al. Association of muscle power with functional status in community-dwelling elderly women. *J Gerontol Med Sci*. 2000;55A:M192–M199.
4. Evans WJ. Exercise strategies should be designed to increase muscle power. *J Gerontol Med Sci*. 2000;55A:M309–M310.

5. Bosco C, Komi PV. Influence of aging on the mechanical behavior of leg extensor muscles. *Eur J Appl Physiol Occup Physiol.* 1980;45: 209–219.
6. Jozsi AC, Campbell WW, Joseph L, Davey SL, Evans WJ. Changes in power with resistance training in older and younger men and women. *J Gerontol Med Sci.* 1999;54A:M591–M596.
7. Skelton DA, Greig CA, Davies JM, Young A. Strength, power and related functional ability of healthy people aged 65–89 years. *Age Ageing.* 1994;23:371–377.
8. Kraemer WJ, Newton RU. Training for muscular power. *Phys Med Rehabil Clin N Am.* 2000;11:341–368, vii.
9. Henwood TR, Taaffe DR. Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. *Gerontology.* 2005;51:108–115.
10. de Vos NJ, Singh NA, Ross DA, Stavrinos TM, Orr R, Fiatarone Singh MA. Optimal load for increasing muscle power during explosive resistance training in older adults. *J Gerontol Biol Sci Med Sci.* 2005;60A:638–647.
11. Cronin J, McNair PJ, Marshall RN. Developing explosive power: a comparison of technique and training. *J Sci Med Sport.* 2001;4:59–70.
12. Siegel JA, Gilders RM, Staron RS, Hagerman FC. Human muscle power output during upper- and lower-body exercises. *J Strength Cond Res.* 2002;16:173–178.
13. Taaffe DR, Pruitt L, Pyka G, Guido D, Marcus R. Comparative effects of high- and low-intensity resistance training on thigh muscle strength, fiber area, and tissue composition in elderly women. *Clin Physiol.* 1996;16:381–392.
14. Schlicht J, Camaione DN, Owen SV. Effect of intense strength training on standing balance, walking speed, and sit-to-stand performance in older adults. *J Gerontol Med Sci.* 2001;56A:M281–M286.
15. Adams KJ, Swank AM, Berning JM, Sevene-Adams PG, Barnard KL, Shimp-Bowerman J. Progressive strength training in sedentary, older African American women. *Med Sci Sports Exerc.* 2001;33:1567–1576.
16. Saboisky J, Marino FE, Kay D, Cannon J. Exercise heat stress does not reduce central activation to non-exercised human skeletal muscle. *Exp Physiol.* 2003;88:783–790.
17. Hakkinen K, Kraemer WJ, Newton RU, Alen M. Changes in electromyographic activity, muscle fibre and force production characteristics during heavy resistance/power strength training in middle-aged and older men and women. *Acta Physiol Scand.* 2001;171:51–62.
18. Moss BM, Refsnes PE, Abildgaard A, Nicolaysen K, Jensen J. Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships. *Eur J Appl Physiol Occup Physiol.* 1997;75:193–199.
19. Henwood TR, Taaffe DR. Short-term resistance training and the older adult: the effect of varied programmes for the enhancement of muscle strength and functional performance. *Clin Physiol Funct Imaging.* 2006;26:305–313.
20. Washburn RA, Smith KW, Jette AM, Janney CA. The Physical Activity Scale for the Elderly (PASE): development and evaluation. *J Clin Epidemiol.* 1993;46:153–162.
21. Powell LE, Myers AM. The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol Med Sci.* 1995;50A:M28–M34.
22. Walters SJ, Munro JF, Brazier JE. Using the SF-36 with older adults: a cross-sectional community-based survey. *Age Ageing.* 2001;30: 337–343.
23. De Vito G, Bernardi M, Forte R, Pulejo C, Macaluso A, Figura F. Determinants of maximal instantaneous muscle power in women aged 50–75 years. *Eur J Appl Physiol Occup Physiol.* 1998;78:59–64.
24. Cronin JB, McNair PJ, Marshall RN. Is velocity-specific strength training important in improving functional performance? *J Sports Med Phys Fitness.* 2002;42:267–273.
25. Van Cutsem M, Duchateau J, Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J Physiol.* 1998;513(Pt 1):295–305.
26. Hakkinen K, Kallinen M, Izquierdo M, et al. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *J Appl Physiol.* 1998;84:1341–1349.
27. Barry BK, Warman GE, Carson RG. Age-related differences in rapid muscle activation after rate of force development training of the elbow flexors. *Exp Brain Res.* 2005;162:122–132.
28. Hakkinen K, Pakarinen A, Kraemer WJ, Hakkinen A, Valkeinen H, Alen M. Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *J Appl Physiol.* 2001;91:569–580.
29. Campos GE, Luecke TJ, Wendeln HK, et al. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. *Eur J Appl Physiol.* 2002;88: 50–60.
30. Beneka A, Malliou P, Fatouros I, et al. Resistance training effects on muscular strength of elderly are related to intensity and gender. *J Sci Med Sport.* 2005;8:274–283.
31. Rhea MR, Alvar BA, Ball SD, Burkett LN. Three sets of weight training superior to 1 set with equal intensity for eliciting strength. *J Strength Cond Res.* 2002;16:525–529.
32. Galvao DA, Taaffe DR. Resistance exercise dosage in older adults: single- versus multiset effects on physical performance and body composition. *J Am Geriatr Soc.* 2005;53:2090–2097.
33. Reeves ND, Narici MV, Maganaris CN. Effect of resistance training on skeletal muscle-specific force in elderly humans. *J Appl Physiol.* 2004;96:885–892.
34. Hunter GR, Wetzstein CJ, McLafferty CL Jr, Zuckerman PA, Landers KA, Bamman MM. High-resistance versus variable-resistance training in older adults. *Med Sci Sports Exerc.* 2001;33:1759–1764.
35. Taaffe DR, Duret C, Wheeler S, Marcus R. Once-weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. *J Am Geriatr Soc.* 1999;47:1208–1214.
36. de Vreede PL, van Meeteren NL, Samson MM, Wittink HM, Duursma SA, Verhaar HJ. The effect of functional tasks exercise and resistance exercise on health-related quality of life and physical activity. A randomised controlled trial. *Gerontology.* 2006;53:12–20.

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