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Lower extremity power training in elderly subjects with mobility limitations: a randomized controlled trial

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Abstract

Background and aims—This study investigated whether high-velocity high-power training (POW) improved lower extremity muscle power and quality in functionally-limited elders greater than traditional slow-velocity progressive resistance training (STR).

Methods—Fifty-seven community-dwelling older adults aged 74.2±7 (range 65-94 yrs), Short Physical Performance Battery score 7.7±1.4, were randomized to either POW (n=23) (12 females), STR (n=22) (13 females) or a control group of lower extremity stretching (CON) (n=12) (6 females). Training was performed three times per week for 12 weeks and subjects completed three sets of double leg press and knee extension exercises at 70% of the one repetition maximum (1RM). Outcome measures included 1RM strength and peak power (PP). Total leg lean mass was determined using dual-energy X-ray absorptiometry to estimate specific strength and specific PP.

Results—During training, power output was consistently higher in POW compared to STR for knee extension (~2.3-fold) and leg press (~2.8-fold) exercises ($p<0.01$). Despite this, PP and specific PP of the knee extensors increased similarly from baseline in POW and STR compared to CON ($p<0.01$), and no significant time-group interaction occurred for PP of the leg extensors. However, gains in leg press specific PP were significantly greater in POW compared to both STR and CON ($p<0.05$). Total leg lean mass did not change within any group.

Conclusions—A short-term intervention of high-velocity power training and traditional slow-velocity progressive resistance training yielded similar increases of lower extremity power in the mobility-impaired elderly. Neuromuscular adaptations to power training, rather than skeletal muscle hypertrophy, may have facilitated the improvements in muscle quality. Additional studies are warranted to test the efficacy of power training in older individuals with compromised physical functioning.

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Conflicts of Interest: None.

Keywords

Aging; exercise; power training

Introduction

Lower extremity muscle power is a strong predictor of physical performance (1), functional mobility (2) and risk of falling (3) among older adults. Muscle power is also inversely associated with functional status in community-dwelling older adults with self-reported disability (4,5) and in elderly subjects with preexisting mobility limitations (2,6).

Exercise interventions targeted at improving lower extremity muscle power in the elderly have been well-tolerated and effective (7-9). Indeed, we have previously reported that an exercise regimen of high-force, high-velocity progressive resistance training (POW) resulted in a twofold increase in muscle power in older women with self-reported functional limitations, compared to traditional high-force, slow-velocity progressive resistance training (STR) (10). However, inherent limitations are associated with the ascertainment of self-reported disability, as individuals may underestimate or overestimate their functional capabilities. In recent years, standardized tests of physical performance have been employed and may offer advantages over self-report measures in terms of validity, reproducibility and applicability (11). Despite this, no study has investigated the effectiveness of POW for improving muscle power in mobility-impaired elders who have been evaluated and classified using a standardized and reliable performance-based assessment of functional ability.

The aim of this study was to explore the effects of POW in elderly subjects who demonstrated compromised physical functioning on the Short Physical Performance Battery (SPPB), which characterizes lower extremity function by assessing gait speed, balance and strength, and is predictive of subsequent disability, institutionalization, and mortality (11,12). We hypothesized that POW would result in greater improvements of lower extremity muscle power compared to STR in this population of frail elders. In addition, we also examined the comparative effects of POW and STR on lower extremity fat free mass and muscle quality.

Methods

Study design

This study was a randomized, controlled 12-week exercise intervention trial comparing the physiological outcomes of POW in older adults with preexisting limitations in physical functioning. All of the training and evaluation sessions were conducted within the laboratory under the supervision of a research assistant. Subjects were recruited from the Boston area through local advertisements and community newsletters. Potential subjects were initially screened by telephone or in person and were considered eligible if they were aged 65 years or older, community dwelling, and demonstrated mild-moderate mobility impairments as defined by a SPPB score ≤9 (11).

Eligible subjects completed a medical history questionnaire and underwent a physical examination and medical screening by the study physician. In addition, all subjects underwent a supervised graded exercise test on a treadmill prior to enrollment. Subjects were excluded from participation if they had acute or terminal illness, myocardial infarction in the past 6 months, unstable cardiovascular disease or other medical condition, upper or lower extremity fracture in the past 6 months, upper or lower extremity amputation, cognitive impairment according to the Folstein Mini-Mental State Examination (MMSE) (score<23), current participation in regular exercise sessions (>1/week), or unwillingness either to complete the study requirements or to be randomized into the intervention or control groups. Other exclusion criteria included uncontrolled hypertension (>150/90 mmHg), the presence of neuromuscular disease or drugs affecting neuromuscular function, and estrogen therapy in females. Subjects meeting the study entry criteria and given medical clearance by the study physician and written approval from their primary care physician were deemed eligible for participation. All volunteers signed an informed consent form and were made aware of all potential risks and benefits associated with procedures of the study prior to enrollment. The Boston University Institutional Review Board approved this study.

Training interventions

After baseline testing participants were randomly allocated to one of the two exercise training groups, or to a control group. A block size of 5 was employed to determine the order in which the interventions were assigned (2 subjects allocated to POW, 2 subjects to STR, 1 subject to control group).

Subjects randomized to POW trained three times per week for 12 weeks. During each session, subjects performed three sets of eight repetitions of bilateral leg press (LP) and individual left and right knee extension (KE) using Keiser pneumatic resistance training equipment (Keiser Sports Health Equipment Inc., Fresno, CA). Subjects were instructed to complete the concentric phase of each repetition as fast as possible, maintain full extension for 1 second, and perform the eccentric phase of each repetition over 2 seconds. Exercise intensity was set at 70% of the subject's one repetition maximum (1RM). After each set, average power and total work performed were calculated and recorded as previously described (10,13).

Subjects randomized to STR also trained three times per week for 12 weeks, performing three sets of eight repetitions of LP and individual left and right KE at 70% of the 1RM. Subjects were instructed to complete the concentric phase, maintain full extension, and perform the eccentric phase of each repetition over 2, 1, and 2 seconds, respectively. The resistance was adjusted biweekly by repeating 1RM measures.

Control intervention

The control intervention consisted of lower extremity range of motion (ROM) and flexibility exercises performed 2 times per week for 12 weeks (CON).

Outcome measures

Muscle Strength and Peak Power—Muscle strength was quantitatively assessed by 1RM measures of LP and individual left and right KE, using the same Keiser pneumatic resistance training equipment used throughout training. The 1RM was defined as the maximum load that could be moved only once throughout the full ROM while maintaining proper form. Subjects performed the concentric phase, maintained full extension, and performed the eccentric phase of each repetition over 2, 1, and 2 seconds, respectively.

After measurement of the 1RM, assessment of LP and individual left and right KE peak muscle power (W) was made after a 5 minute rest for both exercises. Performance of this multiple attempt peak power test has been previously described and validated (13). Briefly, each participant was instructed to complete a total of five repetitions each separated by 30 seconds as quickly as possible through their full ROM at both 40% and 70% of 1RM for LP and KE. The highest measured power (peak power) at 40% and 70% of 1RM was recorded.

Baseline LP and KE 1RM and peak power measures were performed twice, with the second evaluation occurring 7 days after the initial evaluation. The intraclass correlation coefficient (ICC) for repeated 1RM testing of LP and KE was 0.97 and 0.92, respectively. The ICC for

LP and KE peak power testing was 0.89 and 0.86, respectively. The best of the two baseline measures was used as the baseline value. Strength and power assessments were repeated at weeks 2, 4, 6, 8, 10, and 12. Because there were no differences between left and right KE strength and power, data are presented for the left leg only (Table 1).

Body Composition—Dual-energy X-ray absorptiometry was used to determine total leg lean mass at baseline and at week 12 utilizing the Hologic QDR 4500 fan beam scanner (Hologic Inc., Waltham, MA). KE (left leg) and LP (left + right leg) strength and power results were adjusted for total leg lean mass to yield estimates of specific strength (sp1RM) (N/kg) and specific peak power (W/kg) at 40% and 70% of 1RM.

Statistical analysis

Data were analyzed using SPSS statistical software (Version 14.0 for Windows, Chicago, IL). All data were first examined visually and statistically for normality of distribution. Values are presented as means ± standard deviation (SD) unless otherwise stated and an “Intent-to-Treat” analysis was utilized. One-way analysis of variance (ANOVA) was used to determine differences between groups at baseline. Primary and secondary outcome variables were assessed using repeated measures analysis of covariance (ANCOVA) models to identify any differences between groups over time. If a significant F ratio was determined, differences in the mean changes between groups were analyzed using a one-way ANOVA followed by *post hoc* testing (Fishers-least-square-differences-test). Independent samples *t*-tests were used to compare the training intensity between POW and STR. Test/retest reliability of LP and KE repeated measurements were assessed using the ICC. Significance level was set at $p \leq 0.05$.

Results

Recruitment

Of the individuals who responded to recruitment efforts (n=415), 229 completed the telephone pre-screening questionnaire of whom 137 underwent a screening assessment. A total of 71 subjects met the acceptable SPPB score criteria of ≤9, however, 14 subjects were excluded for medical reasons. Therefore, 57 subjects, 14% of the original respondents, were randomized to the POW (n=23) (12 females), STR (n=22) (13 females) and CON (n=12) (6 females) study arms (Fig. 1). One subject from each group withdrew from the study complaining of either sacral-iliac pain following completion of baseline testing (CON), persistent chest pain during (POW) or after the first week of training (STR). Another subject randomized to POW was diagnosed with a benign brain tumor after baseline testing and withdrew from the study. No other adverse events were reported. The training adherence rates (number of training sessions attended / total number of sessions), including all withdrawals, were 82% and 77% in POW and STR respectively, and 80% in CON.

Subject characteristics

Baseline characteristics are presented in Table 1. Age was significantly different between groups [CON *vs.* STR ($p<0.006$) and CON *vs.* POW ($p<0.002$)]. The mean SPPB score at baseline was 7.7±1.4 (min-max: 3-9), which was similar across all groups. One third of the participants had an SPPB score ≤7 (n=19). Over one half of all participants were female (54%), and the racial distribution was as follows: 81% Caucasian, 14% African American, 5% Asian.

Training intensity

To compare the intensity of POW and STR throughout the intervention, training data were analyzed on representative training days that were conducted after the 1RM and peak power measures at baseline and weeks 4 and 8 (Table 2). The relative training force was maintained near the desired goal of 70% of the 1RM in both groups. There were no significant differences between POW and STR for LP and KE training force or total work. However as expected, power output and velocity were both significantly higher in POW compared to STR for KE (~2.3-fold) and LP (~2.8-fold) ($p<0.01$).

Outcome measures

Muscle Strength—KE 1RM strength increased significantly from baseline in STR (41%) and POW (49%) compared to CON ($p<0.01$, Fig. 2a). No significant time-group interaction occurred for LP 1RM (Fig. 2b).

Muscle Power—Both KE peak power at 40% and 70% of 1RM increased significantly from baseline in STR and POW compared to CON ($p<0.01$). However, there was no significant difference in the magnitude of these improvements between POW and STR (Fig. 3a). For LP, no significant time-group interaction occurred for either LP peak power at 40% or 70% of 1RM (Fig. 3b).

No change in total leg lean mass occurred over the course of the intervention in any group ($p=0.71$), therefore the changes in both absolute and specific 1RM for KE and LP were of an equivalent magnitude. KE specific 1RM increased significantly from baseline in STR (44%) and POW (55%) compared to CON ($p<0.01$). Similarly, LP specific 1RM increased significantly in STR (18%) and POW (26%) compared to CON ($p<0.01$). There was no significant difference in the magnitude of the KE or LP specific 1RM increase between STR and POW. Both KE specific peak power at 40% and 70% of 1RM increased significantly from baseline in STR and POW compared to CON ($p\leq0.004$). However, there was no significant difference in the magnitude of these improvements between POW and STR for KE specific peak power at 40% or 70% of 1RM (Fig. 4a). For LP specific peak power at 40% of 1RM, there was a significantly greater improvement in POW (36%) compared to both CON (19%) and STR (18%) ($p<0.05$) (Fig. 4b). Similarly, the difference in LP specific peak power at 70% from baseline was significantly greater in POW (46%) compared to both CON (14%) and STR (20%) ($p<0.05$) (Fig. 4b).

Discussion

The major finding of this study was that in elderly subjects with mild-moderate mobility impairments, a 12-week high-velocity power training intervention induced similar improvements of lower extremity muscle power compared to traditional slow-velocity strength training. This finding was contrary to our primary hypothesis, although both POW and STR did significantly improve KE strength and power, but after adjustment for all possible covariates, group differences in LP strength and power did not reach statistical significance. However, POW was associated with greater improvements in specific LP power compared to both STR and CON. This suggests that gains in muscle quality, which occurred without measurable hypertrophy, may have been due to neural adaptation to this form of explosive resistance training.

Muscle power declines more precipitously than strength in older adults resulting in a dramatic loss in the ability to produce force rapidly. In contrast to STR, POW specifically focuses on maximizing contraction velocity and power development. However, the current data emphasize the challenges associated with developing optimal exercise strategies for clinically relevant outcomes in older adults. The non-significant increases of absolute LP power in response to POW and STR are considerably lower than previous reports in elderly subjects (Table 3) (8,10). Earles et al. (8) reported that 12 weeks of power training resulted in emphatic gains of leg extensor muscle power (150%), at a resistance equivalent to 70% of body mass. Fielding et al. (10) directly compared the outcomes of high velocity power training and traditional slow velocity progressive resistance training over 16 weeks, and found that power training resulted in large improvements of leg extensor power output (97%) at 70% 1RM, which were significantly greater than gains as a result of traditional strength training (45%).

Several important factors may have contributed to the current findings. First, the training duration was shorter than employed in some previous trials, perhaps limiting the training-induced adaptations to power training. However, greater leg power improvements in response to high velocity power training have been reported after only 4 weeks of training in older women with functional limitations (10). Second, previous studies reporting improvements in muscle power assessed participants who were either healthy and high functioning (8,14), or were classified as mobility-impaired through use of self report measurements (10). However, the current study participants, many of whom were at-risk for future disability, were enrolled using a robust assessment of lower extremity physical performance (11). This factor may also explain why the power output values elicited throughout the duration of POW and STR (Table 2) were markedly lower than previously observed (10). Finally, the present study was the first to employ a newly validated methodology to assess lower extremity power in the elderly that minimized any potential learning effects (13). Previous intervention studies using other methodologies may have underestimated leg power in older subjects and subsequently exaggerated the resultant improvements with power training (8,9).

Both exercise training interventions were associated with similar improvements in specific strength and specific KE power compared to CON, but it was only POW subjects that elicited significant gains in specific LP power. Improvements in muscle strength and muscle power without associated alterations in body composition may reflect enhanced neural adaptations in the early stages of training, as reported by others (15). It is likely that the earlier motor unit activation and enhanced maximal firing rates associated with POW would be principle stimuli for neural adaptations to this explosive form of training (16). The fact that total leg lean mass was used to calculate specific power, rather than thigh lean mass, may explain why specific power was improved for the leg extensors and not the knee extensors. However, one limitation of this study is that a comparative assessment of the neuromuscular responses to POW and STR was not performed. Thus, the time-course and magnitude of these training adaptations in older individuals with mobility limitations, as well as an understanding of the mechanism underlying the improvement in muscle quality, remains unknown.

In conclusion, a short-term intervention of high-velocity high-power progressive resistance training was associated with similar improvements of lower extremity muscle power compared to traditional slow-velocity strength training in elderly adults with preexisting mobility impairments. Although both training modalities yielded similar increases of lower extremity strength in this population, high-velocity power training was associated with significant gains in specific muscle power. Training induced neuromuscular adaptations, and not skeletal muscle hypertrophy, may have facilitated the greater increases in muscle quality in response to power training. Future studies should directly quantify neural adaptations to power training to confirm these observations, and further randomized controlled trials are warranted to investigate the optimal training duration and volume required to elicit significant improvements of muscle power, strength and functional performance in elderly subjects who are at increased risk for subsequent disability.

Acknowledgements

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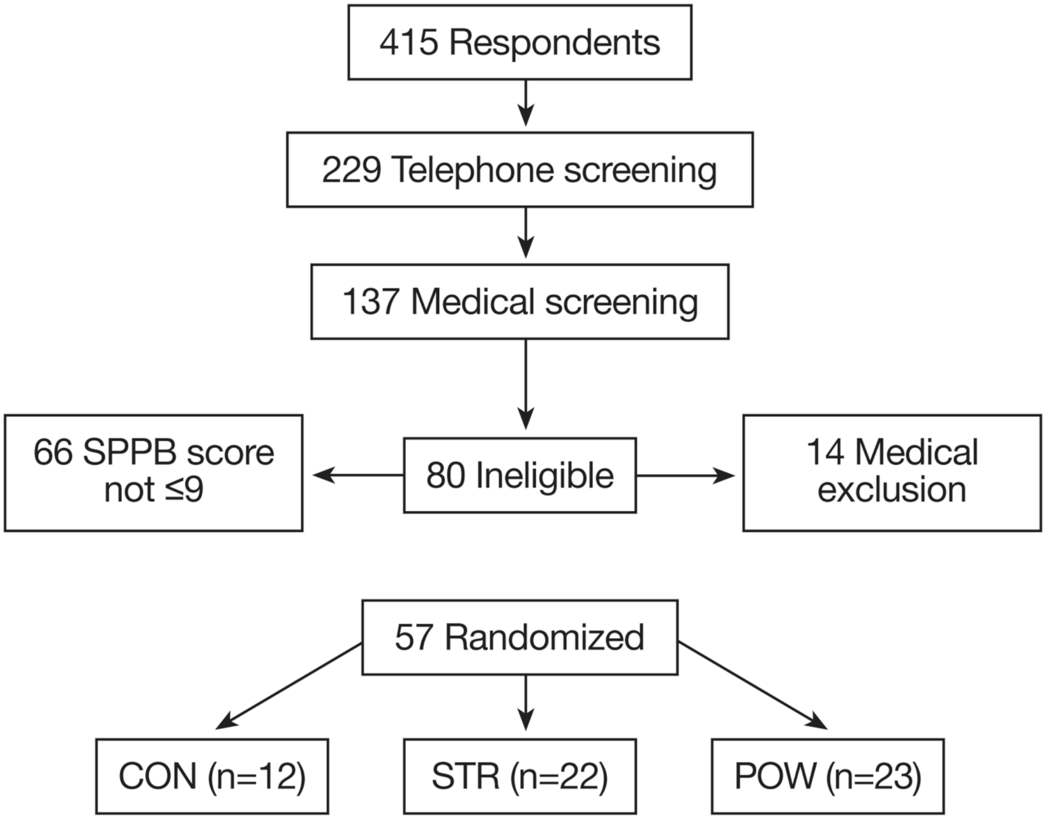

Fig. 1.
Participant flow from initial respondents to randomization.

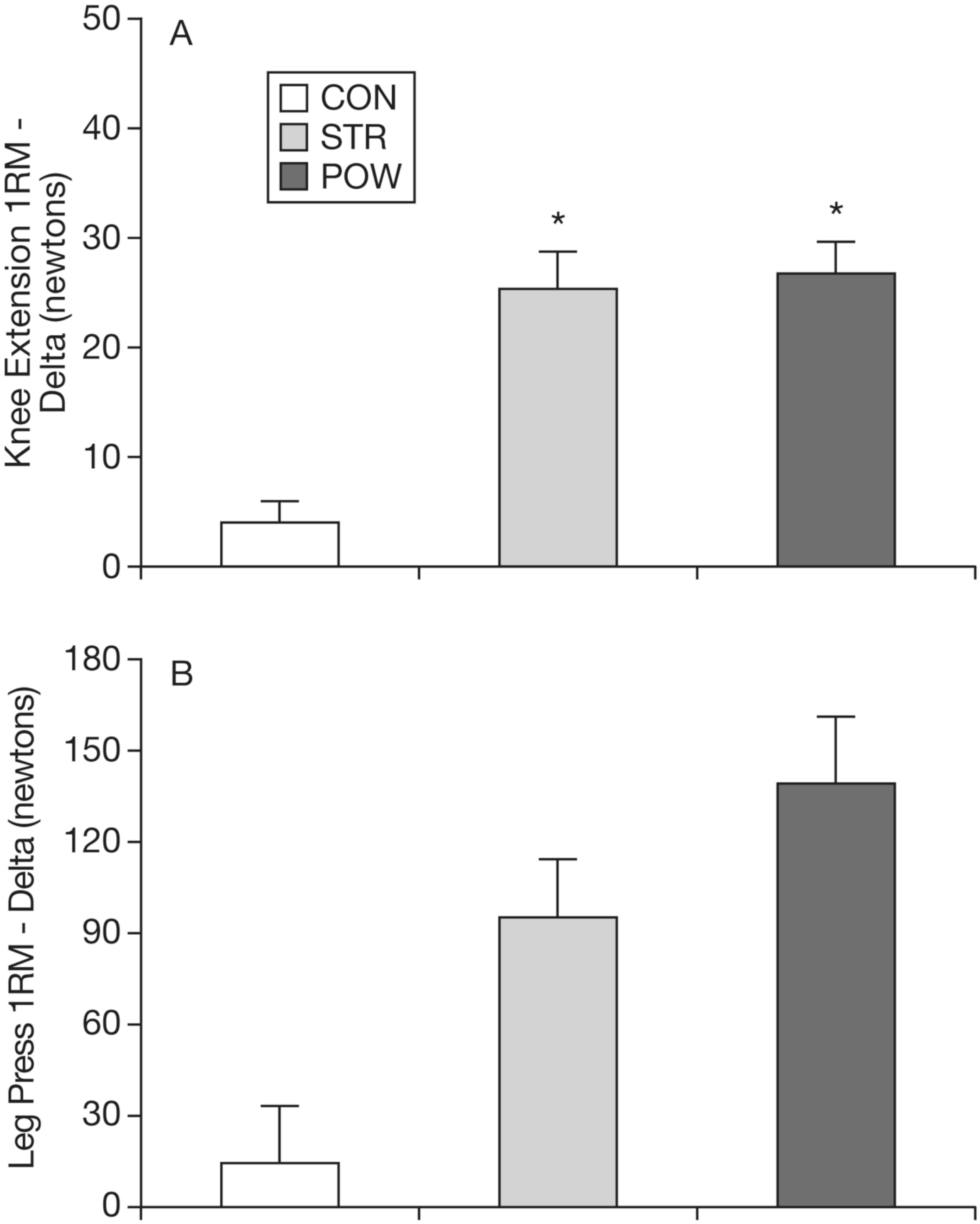

Fig. 2.

A) Change in knee extension absolute strength. Values are mean±SE. ANCOVA model adjusted for age, sex, BMI and baseline value. There was a significant time × group interaction ($p<0.001$) and *post-hoc* comparisons identified the differences: *significantly greater *vs.* CON, $p<0.001$. B) Change in leg press absolute strength. Values are mean±SE. ANCOVA model adjusted for age, sex, BMI and baseline value. There was no significant time × group interaction ($p=0.14$).

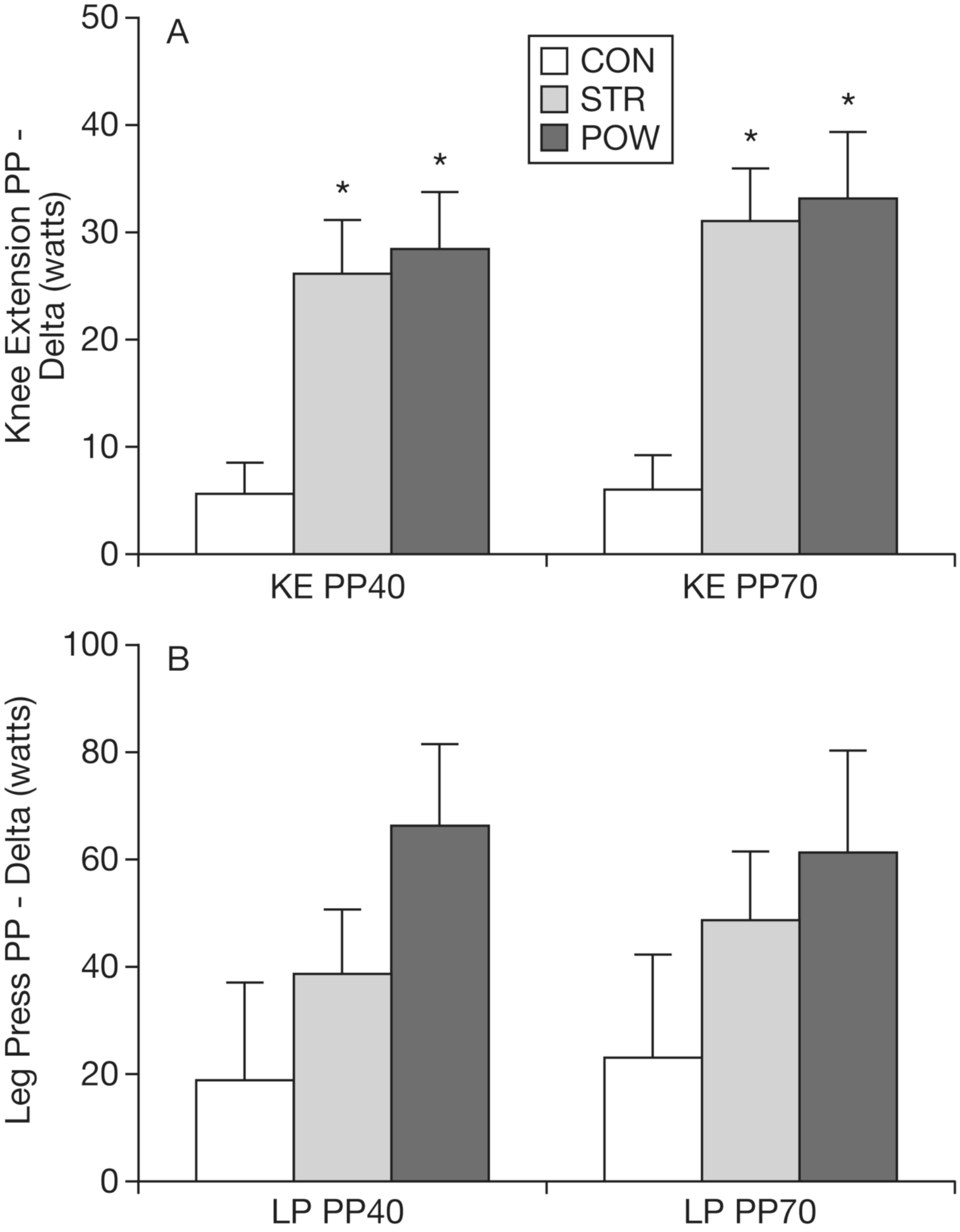

Fig. 3.

A) Change in knee extension absolute peak power at 40% (KE PP40) and 70% (KE PP70) of 1RM. Values are mean±SE. ANCOVA models adjusted for age, sex, BMI and baseline values. There was a significant time × group interaction for PP40 ($p=0.02$) and PP70 ($p<0.05$) and *post-hoc* comparisons identified the differences: *significantly greater vs. CON, $p\leq0.003$. B) Change in leg press absolute peak power at 40% (LP PP40) and 70% (LP PP70) of 1RM. Values are mean±SE. ANCOVA models adjusted for age, sex, BMI and baseline values. There was no significant time × group interaction for PP40 ($p=0.19$) or PP70 ($p=0.22$).

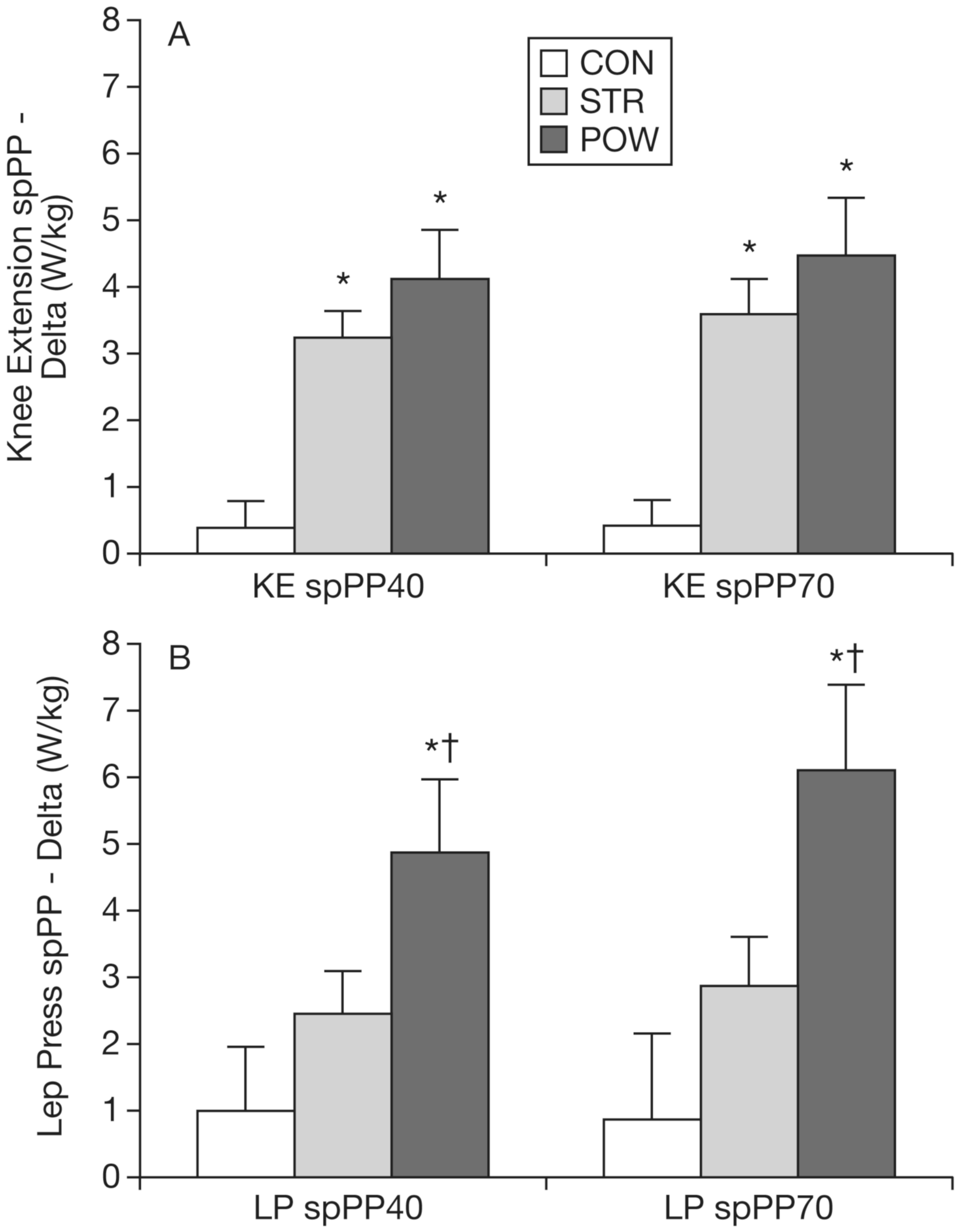

Fig. 4.

A) Change in knee extension specific peak power at 40% (KE spPP40) and 70% (KE spPP70) of 1RM. ANCOVA models adjusted for age, sex, BMI and baseline values. There was a significant time × group interaction for spPP40 (p=0.01) and spPP70 (p=0.03) and *post-hoc* comparisons identified the differences: *significantly greater *vs.* CON, $p \leq 0.004$. B) Change in leg press specific peak power at 40% (LP spPP40) and 70% (LP spPP70) of 1RM. ANCOVA models adjusted for age, sex, BMI and baseline values. There was a significant time × group interaction for spPP40 (p<0.02) and spPP70 (p=0.03) and *post-hoc* comparisons identified the differences: *significantly greater *vs.* CON, $p \leq 0.01$, †significantly greater *vs.* STR, p<0.05.

Table 1

Baseline characteristics

	CON (n=12) (6 females)	STR (n=22) (13 females)	POW (n=23) (12 females)
Age, yr	79.7±9	73.1±6[*]	72.3±6[*]
Body mass, kg	70.2±11	82.0±20	80.9±14
Body mass index, kg/m^2	26.5±4	29.6±7	29.8±6
Medical diagnosis, n	0.9± 1 (0-3)	1.4±1 (0-4)	1.6±1 (0-4)
Medications, n	1.5±2 (0-5)	2.4±2 (0-8)	2.6±2 (0-9)
SPPB	7.4±1.8	8.0±1.2	7.6±1.4
Total leg lean mass, kg	14.0±2	16.2±4	16.0±3
Knee Extension 1RM (N)	58±24	65.2±28	68.3±25
Peak Power 40% (W)	65.6±24	74.1±27	93.5±35[*†]
Peak Power 70% (W)	81.1±28	81.8±44	112±50 [*†]
Leg Press 1RM (N)	535.3±224	595±217	573.9±135
Peak Power 40% (W)	197.5±72	236.4±94	241.3±81
Peak Power 70% (W)	230.8±91	244±99	254±118

Values are mean±SD. SPPB= short physical performance battery score;

[*] Significant difference *vs.* CON ($p \leq 0.02$);

[†] Significant difference *vs.* STR ($p \leq 0.05$).

Table 2

Training intensity: STR vs. POW

	Baseline		Week 4		Week 8	
	STR	POW	STR	POW	STR	POW
Knee Extension						
% 1RM	69.3±6	69.5±4	71.0±6	69.1±8	71.9±5	69.3±4
Force (N)	51±27	48±15	57±32	57±16	67±33	62±16
Work (J)	421±231	429±165	481±240	526±173	532±250	569±158
Power (W)	35±23	77±39[*]	43±35	110±61[*]	55±53	118±54[*]
Velocity (radians/sec)	0.7±0.3	1.5±0.5[*]	0.7±0.6	1.7±0.7[*]	0.8±0.5	1.8±0.7[*]
Leg Press						
% 1RM	70.0±0.1	69.7±4	70.0±3	72.6±5	70.0±3	72.6±5
Force (N)	410±153	406±153	437±174	443±82	479±181	471±90
Work (J)	1590±1476	2032±1971	1388±731	1747±725	1354±699	1651±711
Power (W)	98±64	247±202[*]	93±59	291±155[*]	101±65	296±139[*]
Velocity (radians)	21±14	45±21[*]	20±15	59±25[*]	20±15	58±23[*]

Values are mean±SD.

[*] significant difference *vs.* STR, $p \leq 0.002$.

Table 3

Characteristics of previous power training studies in older adults

	Age	Sex	Participants	Duration	Power Training Intervention
Earles et al. (8)	77±5	65% female	Healthy (n=18)	12 weeks	3 × week, 3 sets × 10 reps for knee extensors, hip extensors (2 × week), plantar and hip flexors. Intensity: 50-70% 1RM, with participants instructed to perform concentric phase of each repetition at usual, ramped or maximal velocities. An additional 45 mins of walking/moderate activity was also included.
Miszko et al. (9)	72±7	55% female	Below-average leg extensor power (n=11)	16 weeks	3 × week, 3 sets × 6-8 reps of multi-joint upper and lower body exercises. Intensity: 50%-70% 1RM for first 8 weeks (slow contraction velocities), changed to 40% 1RM for remaining 8 weeks, with participants instructed to perform concentric phase of each repetition as fast as possible.
Fielding et al. (10)	73±1[*]	100% female	Self-reported functional limitations (n=15)	16 weeks	3 × week, 3 sets × 8-10 reps for knee and hip extensors. Intensity: 70% 1RM, with participants instructed to perform concentric phase of each repetition as fast as possible.
de Vos et al. (14)	69±6	61% female	Healthy (n=84)	8-12 weeks	2 × week, 2-3 sets × 8 reps for upper and lower body multi-joint exercises. Intensity: 20%, 50% or 80% of 1RM, with participants instructed to perform concentric phase of each repetition as fast as possible.

Values are mean±SD.

[*] Standard error.