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High-speed power training in older adults: A shift of the external resistance at which peak power is produced

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Abstract

Studies have shown that power training increases peak power in older adults. Evaluating the external resistance (% one repetition-maximum [1RM]) at which peak power is developed is critical given that changes in the components of peak power (force and velocity) are dependent on the % 1RM at which peak power occurs. The purpose of this study was to compare the changes in peak power (and the external resistance at which peak power occurred) after 12 weeks of high-speed power training versus traditional slow-speed strength training. Seventy-two older men and women were randomized to high-speed power training at 40% of the one-repetition maximum (1RM) (HSPT: n=24 [70.8±6.8 yrs]); traditional RT at 80% 1RM (STR: n=22 [68.6±7.8 yrs]); or control (CON: n=18 [71.5±6.1 yrs]). Measures of muscle performance were obtained at baseline and after the 12-week training intervention. Changes in muscle power and 1RM strength improved similarly with both HSPT and SSST, but HSPT shifted the external resistance at which peak power was produced to a lower external resistance (from 67% 1RM to 52% 1RM) compared to SSST (from 65% 1RM to 62% 1RM)($p<0.05$), thus increasing the velocity component of peak power (change: HSPT=0.18±0.21 m/s; SSST=-0.03±0.15 m/s)($p<0.05$). Because sufficient speed of the lower limb is necessary for functional tasks related to safety (crossing a busy intersection, fall prevention), HSPT should be implemented in older adults to improve power at lower external resistances, thus increasing the velocity component of power and making older adults safer in their environment. These data provide clinicians with the necessary information to tailor exercise programs to the individual needs of the older adult, affecting the components of power.

Keywords

Muscle power; velocity; aging; resistance training; movement speed

INTRODUCTION

Many studies have reported that power training in older adults (i.e., resistance training at higher movement speeds) increases peak power production (10,14,15,17), a critical muscle performance variable in the maintenance of function and independence in this population (3,5,9,11,22). Power is the product of force and velocity, thus an improvement in peak power necessitates a change in the force component or velocity component of power (or both) to bring about that change. What has not been adequately addressed in the literature is

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the contribution of force or velocity to this change in peak power or the change in external resistance at which peak power occurs. The ability to produce power at a lower or higher external resistances (with a concomitant change in the velocity or force component) is critical to different types of functional tasks encountered during everyday tasks. Indeed, becoming more powerful at lower external resistances will increase the velocity component of power, which is critical to tasks related to safety. From a practical standpoint it is more likely an older adult will have to move an object of low external resistance quickly (requiring velocity) than to move an object of high external resistance slowly (requiring force). For example, tasks such as moving the lower limb quickly to stabilize the body after losing balance or from the accelerator to the brake while driving are encountered frequently in this population, but being trapped under a heavy object where maximum strength is required would be encountered rarely. Thus, a training regimen that increases peak power at lower external resistances would be an optimal training result for an older adult interested in practical functioning and maintaining safety with age.

To fully understand the contribution of force and velocity to peak power, evaluating the external resistance at which peak power is developed is critical given that changes in force and velocity are necessarily dependent on the external resistance (% 1RM) at which peak power occurs. Peak power is typically determined by measuring power output at several percentages of the one-repetition maximum (1RM) (3,6,7,8,10,18,19), and choosing the highest power output value across that range of external resistances. Power typically increases as external resistance is increased, reaching a peak between 60-70% 1RM in this population (10) and decreasing at the highest external resistances (10,19,20,21).

In several recent publications, we have advocated for the importance of improving the velocity component of power (i.e., movement speed) because of its potential impact on functional tasks related to safety (20,21). The purpose of this study was to compare the changes in peak power after 12 weeks of high-speed power training versus traditional slow-speed strength training. We hypothesized that high-speed training and slow-speed resistance training would both increase peak power similarly, but high-speed power training would shift the external resistance at which peak power is produced to lower external resistances. By increasing power at lower external resistances, high-speed power training would improve the velocity component of power, which we believe is critical to increasing safety in this population.

METHODS

Experimental Approach to the Problem

We propose to answer the question of whether different resistance training (RT) regimens (high-speed power training vs. traditional RT) applied over 12 weeks will differentially affect peak muscle power and its components (peak power velocity and peak power force) and the external resistance at which that power is produced. By knowing this information, the strength and conditioning coach may be able to tailor exercise programs to affect the components of power, depending on the needs of the older adult. Dependent variables in the study therefore include peak power (the highest power obtained from 40-90% of the 1RM and its components [peak power force and peak power velocity]) and the external resistance (% 1RM) at which peak power occurred. Independent variables in the study consisted of the different training regimens hypothesized to impact the dependent variables differently, high speed power training and traditional slow-speed RT.

Subjects

Seventy-two older men and women were randomized to one of three treatment arms: High-Speed Power Training (HSPT), Slow-Speed Strength Training (SSST) or a no-RT Control Group (CON). All participants were community-dwelling (ambulatory with or without an assistive device). A study physician determined eligibility for all participants to take part in the study. Exclusion criteria consisted of history of heart disease, severe visual impairment, presence of neurological disease, pulmonary disease requiring the use of oxygen, uncontrolled hypertension, hip fracture or lower extremity joint replacement in the past 6 months, and current participation in structured RT exercise. Eight participants withdrew during the intervention, 1 in HSPT, 3 in SSST, and 4 in CON, leaving 64 older men and women (HSPT: n=24; SSST: n=22; CON: n=18) remaining who completed the study. Subject characteristics are presented in Table 1. This research project was approved by the University of Missouri (MU) Institutional Review Board and written informed consent was obtained from all participants.

Procedures

The study compared 12 weeks of explosive HSPT with traditional SSST using leg press (LP) and knee extension (KE) exercises. Because the LP exercise was a multi-joint, closed chain activity which best represented lower extremity function (and to minimize complexity and length of the manuscript), only LP data are presented. Outcome measures in the study included LP one-repetition maximum (1RM), peak power (PP: the highest value observed across a range of external resistances [40%-90% 1RM]), and its corresponding velocity at peak power (PPV) and force at peak power (PPF), and the external resistance at which peak power occurred (% 1RM at PP).

Participants reported to the laboratory for two weeks of baseline measurements. On visit 1, body mass of the fully clothed subject was recorded on a platform scale to the nearest 0.1 kg. Height was measured to the nearest 0.5 cm with a scale stadiometer. Body mass index was calculated from these variables. Cognitive function was assessed using the Mini-Mental State Examination (12) and Geriatric Depression Scale was used to assess depression during the previous seven days (24). The number of falls in the previous year and the number of medications used was also obtained. On visit 2 and 3, muscle performance measures (1RM, PP, PPV, and PPF) were obtained. The following week, all muscle performance measures were repeated to establish reliability. A third set of muscle performance measures was obtained if baseline 1RM measurements deviated by more than 10% from the first to the second week. At the end of baseline testing, participants were randomized to one of the treatment groups or control. Post-training muscle performance measures were obtained after the 12-week intervention. All participants were tested at approximately the same time of day before and after their training regimen to minimize potential daytime variability in muscle performance.

Resistance Training Protocol—Volunteers were randomized into HSPT and SSST and performed LP and KE exercises on computer-interfaced Keiser a420 pneumatic RT equipment (Fresno, CA) 3 times per week for 12 weeks. For HSPT, each training session consisted of 3 sets of 12-14 repetitions at 40% 1RM. Participants performed a maximal high speed movement during the concentric phase of each repetition, paused for one-second, and performed the eccentric portion of the contraction over 2 seconds. Volunteers randomized into SSST performed 3 sets of 8-10 repetitions at 80% 1RM using a slow-speed movement (2-3 seconds) during the concentric phase of the contraction, paused for one-second, and perform the eccentric portion of the contraction over 2 seconds. The HSPT group performed a greater number of repetitions to more closely equate work performed between groups and

to remain consistent with RT guidelines (1). CON met three times a week for similar warm-up and stretching exercises as HSPT and SSST, but performed no RT.

Measures

Maximal strength and power (peak power velocity and peak power force): Leg press and seated knee extension 1RM were obtained using Keiser pneumatic RT equipment fitted with a420 electronics. As the exercise arm is moved through its range of motion, a piston is driven into a cylinder where it encounters the mechanical resistance of the air pressure in the system. The a420 equipment captured measures of PP, PPV and PPF during the concentric portion of each contraction by sampling the system pressure at 400Hz and making calculations based on an appropriate algorithm.

The seat of the recumbent LP and seated KE machines was positioned to place both the hip and knee joint between 90 and 100 degrees of flexion. The 1RM (defined as the maximum pneumatic resistance that could be moved throughout the full range of motion once while maintaining proper form [16]) was obtained by progressively increasing resistance until the subject was no longer able to push out one repetition successfully. Perceived maximal effort using the Borg Scale (4) assisted in the evaluation of 1RM measurement. Peak muscle power was obtained at 40%, 50%, 60%, 70%, 80% and 90% of the 1RM approximately 30 minutes after 1RM testing (8,9). Participants were instructed to exert “as fast as possible” during three attempts at each of these resistances. The greatest PP output obtained across all external resistances was used in the analysis. The corresponding PPV and PPF were obtained. The 1RM was measured bi-weekly in the RT groups only and relative training intensity was adjusted accordingly to ensure HSPT and SSST were training at 40% 1RM and 80% 1RM, respectively, throughout the 12-week intervention.

Percent 1RM at peak power: To calculate the average external resistance at which peak power occurred, we summed the % 1RM values at PP for all groups. This calculation was performed for both the baseline and post-training value.

Statistical Analyses

Descriptive statistics were run on all variables. Associations among variables of age, sex, body mass index, cognitive function, depression, medications, and falls were evaluated using Pearson's *r*. When significant associations were found, those variables were used as covariates in all analysis of variance (ANOVA) models. When no significant main effects or interactions were found in full ANOVA models, a reduced model was run without the covariate. In all ANOVA models, the assumption of normality and homogeneity of variances was assessed. In repeated measures ANOVA models, when equal variances were not observed using Mauchley's test of sphericity, corrections to the F-ratio were applied using Greenhouse-Geisser Epsilon values.

To evaluate baseline differences in subject characteristics, a one-way ANOVA (continuous variables) or Chi square (categorical variables) was run. To evaluate baseline differences among groups in LP muscle performance (1RM, PP [and its corresponding PPV and PPF value]), a one-way ANOVA was performed. Reliability and consistency of baseline measures were assessed using Intraclass R and repeated measures ANOVA. The coefficient of variation (%CV) was used to measure the dispersion of the baseline variables.

To evaluate differences among groups in LP peak muscle performance from baseline to post-testing (hypothesis 1), a 3×2 (group by time) repeated measures ANOVA was run. Effect sizes were obtained using partial Eta squared. To evaluate differences in the % 1RM at PP (hypothesis 2), a 3×2 (group by time) repeated measures ANOVA was also run. If

significant group main effects or interactions were found, post-hoc testing on the change score (post-training minus baseline value) using Tukey's HSD test was performed. Statistical significance for all tests was accepted at $p < 0.05$. Data are reported as means \pm SD.

RESULTS

At baseline, there were no differences among groups in age, sex, body mass index, depression, cognitive function, number of medications or falls in the past year (see Table 1). There were also no baseline differences among the groups in LP 1RM (HSPT: 1441 ± 419 N [95% CI: 1,264 to 1,618N]; SSST: 1429 ± 492 N [95% CI: 1,211 to 1,647W]; CON: 1295 ± 376 N [95% CI: 1,108 to 1,482N]), PP (HSPT: 835 ± 337 W [95% CI: 694 to 997W]; SSST: 903 ± 394 W [95% CI: 728 to 1,078W]; CON: 755 ± 258 W [95% CI: 627 to 884W]), PPV (HSPT: 0.90 ± 0.21 m/s [95% CI: 0.81 to 0.99m/s]; SSST: 0.98 ± 0.12 m/s [95% CI: 0.93 to 1.03m/s]; CON: 0.91 ± 0.17 m/s [95% CI: 0.83 to 1.0m/s]), or PPF (HSPT: 917 ± 269 N [95% CI: 803 to 1,030N]; SSST: 912 ± 354 N [95% CI: 755 to 1,068N]; CON: 826 ± 214 N [95% CI: 818 to 961N]) (all $p > 0.05$). Reliability and consistency for baseline variables were as follows: LP 1RM (ICC: $R = 0.94$; ANOVA: $p > 0.05$), LP PP (ICC: $R = 0.98$; ANOVA: $p > 0.05$), LP PPV (ICC: $R = 0.78$; ANOVA: $p > 0.05$), LP PPF (ICC: $R = 0.90$; ANOVA: $p > 0.05$). The %CV for LP 1RM, LP PP, LP PPV and LP PPF was 6.4%, 6.1%, 9.9%, and 9.8%, respectively.

From baseline to post-training, there were significant differences in muscle performance variables (see Figure 1). There was a significant group by time interaction for LP 1RM ($p < 0.001$; partial Eta squared = 0.27), LP PP ($p = 0.003$; partial Eta squared = 0.17) LP PPV ($p = 0.001$; partial Eta squared = 0.22), and LP PPF ($p = 0.001$; partial Eta squared = 0.19). Post-hoc tests showed that the change in LP 1RM was significantly different when comparing HSPT (310 ± 213 N) and CON (103 ± 131 N) ($p = 0.002$; mean difference = 207N [95% CI: 69 to 346N]) and SSST (368 ± 189 N) and CON ($p < 0.001$; mean difference = 265N [95% CI: 124 to 407N]), with no difference between HSPT and SSST ($p = 0.54$; mean difference = -58N [95% CI: -189 to 73N]). Post-hoc tests showed that the change in LP PP was significantly different when comparing HSPT (186 ± 131 W) and CON (31.7 ± 130) ($p = 0.002$; mean difference = 155W [95% CI: 49 to 261W]) and SSST (144 ± 160 W) and CON ($p = 0.04$; mean difference = 112W [95% CI: 4.0 to 220W]), with no difference between HSPT and SSST ($p = 0.57$; mean difference = 43W [95% CI: -58 to 143W]). Post-hoc tests showed that the change in LP PPV was significantly different when comparing HSPT (0.18 ± 0.21 m/s) and SSST (-0.03 ± 0.15 ms) ($p = 0.001$; mean difference = 0.22m/s [95% CI: 0.09 to 0.35m/s]) and HSPT and CON (0.02 ± 0.18 m/s) ($p = 0.02$; mean difference = 0.16m/s [95% CI: 0.02 to 0.29m/s]), with no difference between SSST and CON ($p = 0.55$; mean difference = -0.06m/s [95% CI: -0.20 to 0.08m/s]). Post-hoc tests showed that the change in LP PPF was significantly different when comparing SSST (184 ± 183 N) and HSPT (10.0 ± 164 N) ($p = 0.003$; mean difference = 174N [95% CI: 54 to 295N]) and SSST and CON (17.2 ± 161 N) ($p = 0.008$; mean difference = 167N [95% CI: 37 to 297N]), with no difference between HSPT and CON ($p = 0.99$; mean difference = -7.0N [95% CI: -135 to 120N]).

Percent 1RM at peak power

There was no difference in the external resistance at which peak power occurred at baseline among groups (HSPT: 67.1 ± 12.3 % 1RM [95% CI: 62 to 72% 1RM]; SSST: 65.5 ± 11.0 % 1RM [95% CI: 61 to 70% 1RM]; CON: 65.0 ± 13.8 % 1RM [95% CI: 58 to 72% 1RM]; ANOVA, $p = 0.84$). Following 12 weeks of RT, there was a significant group by time interaction ($p = 0.009$; partial Eta = 0.14). Post-hoc tests showed that the change in % 1RM at PP was significantly different when comparing HSPT (-14.6 ± 12.5 % 1RM) and SSST (-3.2 ± 13.6 % 1RM) ($p = 0.02$; mean difference = -16% 1RM [95% CI: -0.31 to -0.02% 1RM]) and HSPT and CON (-3.3 ± 15.3 % 1RM) ($p = 0.03$; mean difference = -17% 1RM [95% CI:

-0.33 to -0.01% 1RM]), with no difference between SSST and CON ($p=0.99$ mean difference=-0.00% 1RM [95%CI: -.16 to 16% 1RM]) (see Figure 1).

DISCUSSION

This study demonstrated that only high-speed power training shifted the external resistance at which peak power was produced to a lower external resistance, thus increasing the velocity component of peak power. We believe these are critical findings for this population and should be considered when developing RT protocols for older adults. While force will always be a necessary component of physical functioning, being able to move quickly, whether getting across the street, moving the limb after losing balance or slamming on the brakes to avoid an accident, may be a more meaningful performance variable. Becoming more powerful at lower external resistances and increasing the velocity component of power will, from a practical standpoint, improve speed-related performance and keep older adults safer in their environment.

In the present study, we observed similar increases in peak power with HSPT and SSST, but we saw differences in the velocity and force components of peak power (HSPT: 25% increase in PPV; SSST: 19% increase in PPF). To fully understand the contribution of force and velocity to peak power, evaluating the external resistance at which peak power is developed is critical given that changes in force and velocity are linked to the external resistance at which peak power occurs. In the present study, we found a greater shift in the % 1RM at PP with our HSPT protocol, -19% (from 67% 1RM at baseline to 52% 1RM post training) which was significantly lower than the shift in SSST and CON (from 65% 1RM at baseline to 62% 1RM post training; -3%). Previous studies have shown that power training at 20%, 50%, 80% 1RM and control resulted in a modest shift to a lower % 1RM at PP (1%-3%) with no differences among the training groups (8). Force tended to be the predominant contributor to PP after power training (8), perhaps due to the higher external resistance at which peak power was produced. However, trends toward greater contributions of velocity to PP at the low training resistances (20% 1RM) compared to high (80% 1RM) were observed (8), while other studies have also shown modest changes in movement velocity with power training compared to strength training (13). The greater magnitude of difference in % 1RM at PP in the present study could be attributed to differences in study protocol, for example the evaluation of one lower body muscle group compared to a composite of five “whole body” exercises reported previously (8).

As an adaptation to high-speed training, producing greater power (and movement speed) at lower external resistances may have greater value in the older adult than improvements in power at higher external resistances (and greater force). For the performance of any functional tasks, there is a necessary level of strength required, but additional strength above a threshold value may not contribute significantly to improvements in function (2). For example, if one has the necessary strength to climb a flight of stairs, getting stronger will not improve one's ability to perform this task. But for many tasks, speed-power may be a greater attribute to focus on, especially with regard to public health. We have shown in a previous study that high-speed power training improves lower limb movement speed from the gas pedal to the brake by 15% compared to slow-speed strength training (20). Crossing a busy intersection within the allotted time of a typical pedestrian traffic signal likely requires a greater velocity component of power than force component. Considering falls in older adults, sufficient strength of the limb is clearly necessary to support the body's weight and prevent a tripper from becoming a faller, however, without the necessary velocity to position the limb quickly, the aforementioned strength is superfluous. There are probably few instances in the life of an older adult (besides the unlikely event of being trapped under a heavy object) that force-power would be more advantageous than speed-power.

Both HSPT and SSST demonstrated similar increases in LP strength (23% and 28%, respectively) and peak power (26% and 17%, respectively) compared to CON. It is interesting to note that HSPT demonstrated these similar increases in LP strength compared to SSST despite HSPT performing RT exercise at half the external resistance of SSST. Although these findings are similar to what has been reported in older women by Taaffe et al. (23) using slow-velocity training, these findings have not been shown in other studies exploring high-speed training. For example, Orr et al. (18) reported that power training at 3 different external resistances (20%, 50%, and 80% 1RM) resulted in increases in the 1RM with each increase in external resistance. Despite inconsistent finding in the literature, we believe that our work and that of Taaffe (23) underscore the importance of getting older adults to engage in RT using even moderate resistances. It appears that the relative untrained state of older adults makes them amenable to increases in muscle strength, which may obviate the need for a more strenuous, slow-speed exercise at high external resistances. However, the addition of the high-speed component of training with moderate external resistances employed in the present study may confer the additional benefits of improved muscle power and velocity.

PRACTICAL APPLICATIONS

Clinicians now have the information to tailor their exercise prescription using the pneumatic RT equipment used in this study to affect the components of power. By training at higher speeds and lower external resistances, the peak power developed will occur at lower external resistance, which increases the velocity component of power. By increasing velocity, an older adult can increase their lower limb movement speed which is required for functional tasks related to safety. In addition, older adults will demonstrate the same overall increases in strength and power that we see when training at more strenuous slower speeds and higher external resistances. While a younger population may benefit from a more traditional slow-speed RT program, which might be prescribed to improve the force component of power to help the performance of an Olympic-style lift, an older adult may benefit more from a high speed power training program to improve the velocity component of power, thus improving their practical functioning and making this population safer.

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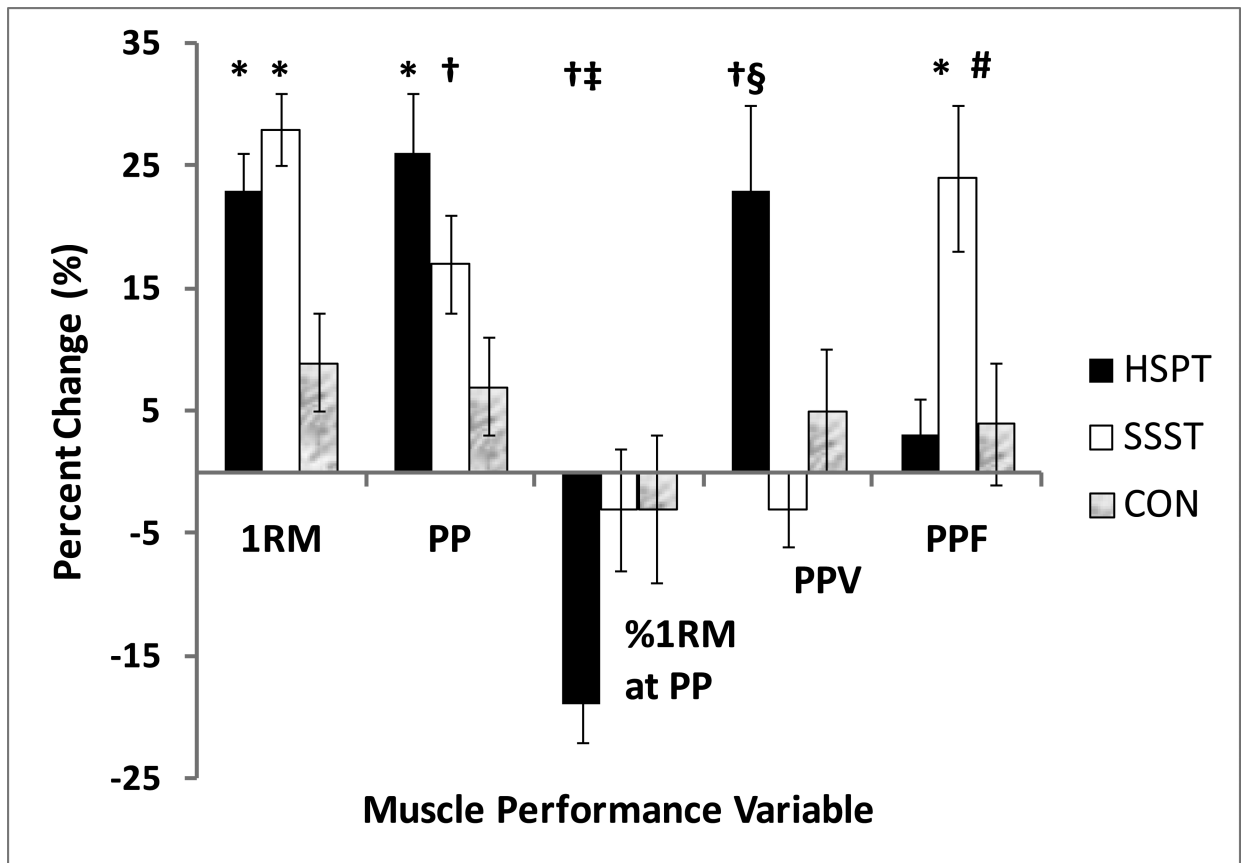


Figure 1.

Percent change in muscle performance variables after 12 weeks of high-speed power training (HSPT), slow-speed strength training (SSST), or Control (CON). 1RM=One-repetition maximum; PP=Peak power; %1RM at PP=External resistance at which peak power occurred; PPV=Peak power velocity; PPF=Peak power force.

* >CON (p 0.01)

† >CON (p 0.05)

‡ >SSST (p 0.05)

§ >SSST (p 0.01)

>HSPT (p 0.01)

Table 1

Participant Characteristics.

	HSPT (n=24)	SSST (n=22)	CON (n=18)	p value
Age (yrs)	70.8±6.8	68.6±7.8	71.5±6.1	0.40
Sex	9m, 15 f	7m 15f	5m 13f	0.80
BMI	27.2±5.5	29.5±7.2	30.0±6.5	0.30
GDS (0-30)	4.9±4.1	6.3±4.2	5.5±3.6	0.48
MMSE (0-30)	28.5±1.4	28.5±2.2	28.6±1.0	0.97
Medications (no.)	5.2±4.2	4.3±2.8	5.8±3.4	0.40
Falls in past year (no.)	3/24	7/24	3/18	0.24

HSPT=High-speed power training; SSST=Slow-speed strength training; CON=Control. BMI=Body Mass Index; GDS=Geriatric Depression Scale; MMSE=Mini-Mental State Examination.