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ORIGINAL ARTICLE

Improvement in functional performance with high-speed power training in older adults is optimized in those with the highest training velocity

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Abstract
Purpose To identify whether variability in limb movement velocity during high-speed power training (HSPT) may impact physical functioning in older adults.
Methods 42 older men and women (71.3 ± 6.6 years) were randomized to lower extremity HSPT ($n = 28$) or control (CON; $n = 14$) (Analysis 1) for 12 weeks. A second analysis (Analysis 2) allocated HSPT into high-velocity ($n = 14$) or low-velocity ($n = 14$) based on a limb movement speed above or below the median average velocity during the 12-week HSPT intervention. Habitual gait speed, maximal gait speed, timed up-and-go, and the short physical performance battery were measured at baseline and 12 weeks. Change scores were compared between HSPT and CON (Analysis 1), and high-velocity, low-velocity, and CON (Analysis 2) using ANCOVA. Statistical significance was accepted at $p < 0.05$.
Results Analysis 1 There were no group differences in habitual gait speed, maximal gait speed, or timed up-and-go between HSPT and CON (all $p > 0.05$). Short physical performance battery was greater in HSPT (0.96 ± 0.19) compared to CON (0.10 ± 0.26; $p = 0.01$). *Analysis 2* There were no group differences in the change in habitual GS ($p = 0.33$) among high-velocity, low-velocity and CON. There were significant group differences in the change in maximal GS ($p = 0.007$), timed up-and-go ($p = 0.03$), and short physical performance battery ($p = 0.03$).
Conclusions There is considerable variation in self-selected maximal limb velocity during HSPT in older adults. In the present cohort, an average limb velocity of 0.88 m/s during HSPT was necessary to ensure optimal improvement in functional performance for older adults, but this threshold will need further investigation.

Keywords Average velocity · Power training · Aging · Functional performance

Abbreviations

1RM	One-repetition maximum
ANCOVA	Analysis of covariance
AV	Average velocity
BMI	Body mass index
CON	Control
GDS	Geriatric depression scale
GS	Gait speed (habitual and maximal)
HI-V	High-velocity training group within HSPT with limb movement speed >0.88 m/s
HSPT	High-speed power training
ICC	Intraclass correlation
KE	Knee extension
LO-V	Low-velocity training group within HSPT with limb movement speed <0.88 m/s
LP	Leg press
MEDS	Number of medications taken
MMSE	Mini-mental state examination
RT	Resistance training
SPPB	Short physical performance battery
TUG	Timed up-and-go

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Introduction

Power training in older adults is a type of resistance training (RT) that emphasizes high-velocity movements using various external resistances. Studies have established that power training is successful in improving measures of muscle performance and some measures of function (Steib et al. 2010; Tschopp et al. 2011), suggesting that velocity of movement is critical to performance outcomes. Studies in young, athletic populations have established that there are optimal velocities at which to perform RT to maximize performance benefits; for example, utilizing an RT average velocity of 0.75–1.0 m/s compared to 1.0–1.5 m/s will optimize a different aspect of strength-power continuum, benefiting athletic performance differently (Jandacka and Beremlijski 2011; Jidovtseff et al. 2009; Mann et al. 2015; Roman 1986). While numerous power training studies have been performed in the older population over the past 30 years, there are little data on whether there is an optimal velocity at which older adults should train to enhance specific functional performance tasks.

Over the past decade, our laboratory has developed and refined high-speed power training (HSPT), a type of training method that emphasizes high-velocity, explosive movements at low external resistances (40 % of the one-repetition maximum [1RM]). We differentiate HSPT from traditional methods of power training that use external resistances above 40 % 1RM, i.e., 50–80 % 1RM, which require slower limb movement speeds during training compared to HSPT due to the force–velocity relationship. HSPT has been shown to improve muscle performance variables of strength, power and movement velocity (Sayers 2007; Sayers and Gibson 2010, 2012, 2014; Sayers et al. 2012); however, its effects on traditional mobility-based functional performance tasks has been mixed, with several studies showing only small changes in half or fewer of the functional tasks examined compared to control (Caserotti 2010; Henwood et al. 2008). Previously, our lab found no improvements in measures of normal gait velocity, chair rise time, and static and dynamic balance after HSPT compared to a non-resistance trained control group (Sayers et al. 2012). These findings are also consistent with that of traditional slow-speed strength training on function, which has shown small to moderate effects on only certain functional tasks in reviews and meta-analyses (Keysor and Jette 2001; Latham et al. 2004).

We have speculated that the lack of transfer of HSPT to function may be due to the nature of the functional tasks, many of which do not encompass a predominant velocity component. Because positive transfer to task performance is most likely when muscle activation patterns reinforced with training are most similar to those required by the functional task (Barry and Carson 2004), the transfer of velocity-based training may not always be specific to the tasks being evaluated. We have also suggested that a lack of improvement in function with power training may be because healthier populations of older adults in these studies are closer to their functional threshold (Buchner et al. 1996), with less ability to see changes in function (Sayers and Gibson 2012).

Alternatively, it may be appropriate to examine more closely the actual velocity generated during HSPT. Given that external resistance is typically quite low during HSPT 40 % 1RM, velocity of movement must be the primary stimulus (and of sufficient magnitude) to impart a training effect. We are finding a large variability in training velocity demonstrated by research participants within the same high-speed training group. Despite instructing participants to move the weight "as fast as possible" during HSPT (Bottaro et al. 2007; de Vos et al. 2008; Fielding et al. 2002; Henwood et al. 2008, Henwood and Taaffe 2005; Katula et al. 2008; Marsh et al. 2009; Pereira et al. 2012; Piirainen et al. 2014; Reid et al. 2008; Reid et al. 2015; Sayers 2007; Sayers and Gibson 2010, 2012, 2014; Sayers et al. 2012), there can be considerable variability among participants in self-selected movement velocity given the broad range of ages, strength, power and functional abilities of older participating in an exercise trial. As a result, there is little control of the velocity component of the exercise, despite ensuring that all participants exercise at the same relative percentage of the 1RM.

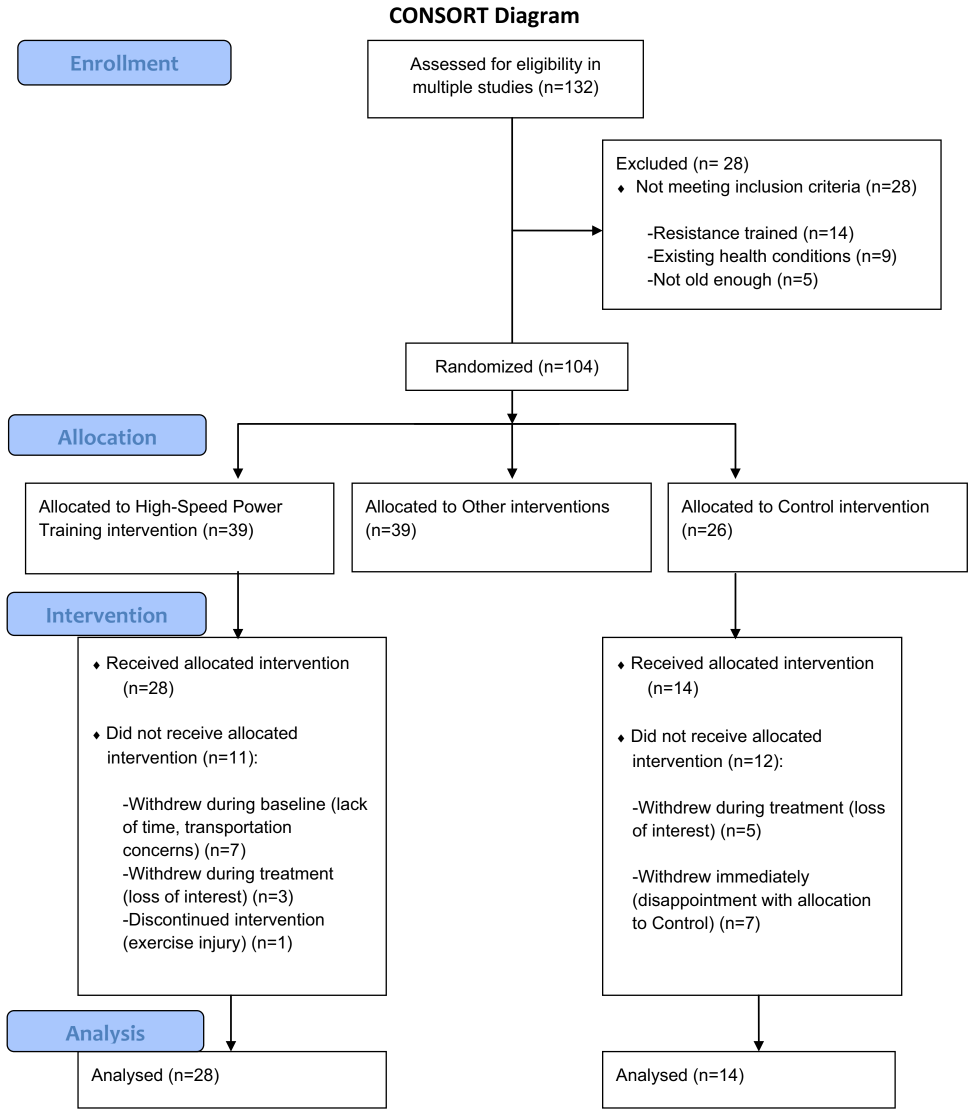
The purpose of this study was to examine lower limb velocity during HSPT and identify whether variability in limb movement velocity within the same high-speed training group may impact physical functioning in older adults. We hypothesized that participants who generate the greatest lower limb velocity during HSPT would demonstrate the greatest improvements in function after 12 weeks of training compared to those who generate the least lower limb velocity during HSPT and a non-resistance trained control group.

Methods

Participants

Overall, 42 older men and women [16 m, 26f; age = 71.3 ± 6.6 years; body mass index (BMI) = 28.3 ± 5.9] from separate studies were included in the present analysis. Eligible participants were aged 65–90 years, ambulatory with or without an assistive device (cane or 3 post walker only) and community dwelling. Exclusion criteria included history of heart disease, neurological disease, or pulmonary disease requiring use of oxygen; severe visual impairment; uncontrolled hypertension;

Fig. 1 Participant flow through the study



hip fracture or lower extremity joint replacement in the past 6 months; current participation in structured exercise. Informed consent was obtained from all individual participants included in this study.

One hundred and thirty-two adults 65 years of age or older were recruited through advertisement in a local mid-Missouri newspaper to participate in separate studies in our laboratory. Twenty-eight did not meet study criteria. Of the 104 who did meet study criteria, 65 were allocated to the HSPT or CON group being compared in the present analysis, while 39 were allocated to other RT interventions not analyzed here. Thirty-nine of the 65 current study participants were randomized to lower extremity explosive HSPT using leg press (LP) and knee extension (KE) RT exercise for a 12-week intervention. The remaining 26 participants were randomized to a control group (CON) who did not participate in the exercise regimen. Of the 39 HSPT participants, 28 completed the study. Adherence to the exercise protocol was excellent with 28/32 participants who began the HSPT intervention continuing until completion (88 %). Only one of the withdrawals from the HSPT group was study related. Of the 22 control participants, 14 completed the study (See CONSORT diagram Fig. 1).

Randomization was performed using a computer-based random numbers generator. Treatment allocations were concealed in sealed envelopes until the time of randomization to minimize selection bias. Neither the investigator nor participant knew which treatment to be assigned at the time of enrollment. Blinding of treatments was not possible during the intervention since both the participants as well as the exercise trainers had knowledge of exercise or control group allocation. A separate investigator assessing baseline and post-training outcome measures was blinded to the participant's group allocation.

Procedures

All study procedures were approved by the University of Missouri Institutional Review Board. The study compared 12 weeks of explosive HSPT in older men and women against a non-exercise control group. Mobility-based functional outcome measures consisted of habitual gait speed (GS), maximal GS, the Timed Up-and-Go (TUG), and the Short Physical Performance Battery (SPPB). Muscle performance was measured using the leg press (LP) one-repetition maximum (1RM). On the first baseline visit, the body mass of each participant was recorded on a standard platform scale. Height was measured with a scale stadiometer. Body mass index (BMI) was calculated from these variables. Global cognitive function was assessed by the Mini-Mental State Examination (MMSE) (Folstein et al. 1975) an instrument ranging from 0 (severe dementia) to 30 (normal). The Geriatric Depression Scale (GDS), a questionnaire containing 30 yes/no questions to assess depressive symptoms during the previous 7 days, was also administered (Yesavage et al. 1982). A score greater than 9 indicates the increasing severity of clinical depression in community dwelling elderly. Number of daily medications (MEDS) was assessed via medical history questionnaires. On the second and third baseline visits, functional outcome and muscle performance measures (described below) were obtained. The following week, all functional outcomes and muscle performance measures were repeated to establish reliability. The average of the two functional outcome and muscle performance measures was used in all analyses. If baseline 1RM measurements deviated by more than 10 % from the first to the second attempt, a third measure was obtained. After the 12-week intervention, post-training functional outcome and muscle performance measures were obtained.

Two separate analyses were carried out in this study. In Analysis 1, changes in functional performance were compared between the HSPT and CON groups. In Analysis 2, participants of HSPT were retrospectively allocated to either a high-speed (HI-V) or low-velocity (LO-V) group for further analysis based on the median lower limb average velocity of each LP repetition during the 12-week HSPT intervention. Fourteen HSPT participants with lower limb movement speeds above the median average velocity were allocated to HI-V, while 14 HSPT participants with lower limb movement speeds below the median average velocity were allocated to LO-V. Changes in functional outcome and muscle performance measures were then compared among HI-V, LO-V and CON.

These analyses were not planned a priori. We combined the data from separate studies to maximize the number of HSPT participants to carry out the proposed analyses. None of the functional outcome data presented here have been published elsewhere.

Assessment of the 1RM

Assessment of the 1RM was necessary to determine the appropriate training intensity (40 % 1RM) for all participants of HSPT. It was also used to ensure that the HSPT protocol was a sufficient stimulus to result in muscle adaptation. LP and seated KE 1RM were obtained using Keiser a420 pneumatic (air resistance) equipment (Fresno, CA). During the concentric actions 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 captures muscle performance measures during the concentric portion of each contraction by sampling the system pressure at 400 Hz and making calculations based on an appropriate algorithm. For brevity, only LP data are described and presented.

The recumbent LP apparatus was adjusted to provide support to the spinal column during 1RM assessments. In the starting position, the seat was positioned to place the knee joint between 90° and 100° of flexion. In this position, the hips were in a similar degree of flexion. Subjects were instructed to extend both legs fully but short of locking the knee joint. The 1RM is defined as the maximum load that can be moved throughout the full range of motion once while maintaining proper form (McDonagh and Davies 1984). The 1RM was obtained by progressively increasing resistance until the subject was no longer able to push out one repetition successfully. Perceived exertion using the Borg Scale (Borg 1970) was used throughout the 1RM procedure, to help identify appropriate increases in load and to assist in evaluating when 1RM (combined with perceived maximal effort) was reached. Once the 1RM was determined, the training intensity of 40 % of the 1RM value was calculated for the 12-week intervention. The 1RM was measured bi-weekly and relative training intensity was adjusted accordingly to ensure adequate overload during training.

Resistance training protocol

Volunteers randomized into HSPT exercised 3 times per week for 12 weeks using computer-interfaced Keiser a420 pneumatic LP and seated KE RT equipment (Fresno, CA). For HSPT, each training session consisted of 3 sets of 14 repetitions at 40 % 1RM. Participants performed the concentric portion of each contraction at a self-selected maximal speed (i.e., "as fast as possible"), paused for 1 s, and performed the eccentric portion of the contraction over 2–3 s. CON met three times a week to participate in warm-up and stretching exercises, but performed no RT exercise. HSPT also participated in the same warm-up and stretching exercises as CON prior to their training.

Assessment of lower limb average velocity

Lower limb average velocity (AV) was assessed using the Keiser a420 equipment. The a420 software calculated lower limb AV of each LP repetition for the left and right legs during each training session. The total number of repetitions analyzed represented the sum of 42 left and 42 right repetitions performed during each exercise session (3 sets × 14 repetitions × 2 lower limbs = 84 repetitions) multiplied by 36 exercise sessions ($n = 3024$) for each of the 28 HSPT participants ($n = 84{,}672$). The median value for lower limb AV was then used to allocate participants of HSPT into HI-V (above the median AV) or LO-V (below the median AV) groups.

Functional outcome measures

Habitual and maximal gait speed Habitual and maximal GS were measured using a stopwatch. Two pieces of tape were placed on the floor 10 m apart. For habitual GS, the participants began with their toes on the edge of the first piece of tape and were instructed to walk all the way past the second piece of tape "at your normal walking speed, as if you were walking down the street to go to the store." For maximal GS, the same procedure was followed except that participants were instructed to walk between the tape at the "fastest walking speed you can go without feeling unsafe or out of control." The stopwatch was started at the initiation of movement and stopped when one foot was completely over the second piece of tape. Each of the habitual GS and maximal GS tests were performed twice, and the average of the two trials was used for analysis. Gait speed was calculated from the distance walked divided by the time to complete the task. Gait speed has been shown to have a good association with lower extremity strength (Guralnik et al. 1994) and slow gait speed is associated with institutionalization and mortality in older adults (Guralnik et al. 2000).

Timed up-and-go The TUG was also measured using a stopwatch. Participants were seated on a standard chair with their back against the back rest and feet flat on the floor in front of them. A cone was placed 3 m in front of the chair. When prompted, the participant stood up from the chair, walked around the cone and back to the chair at their normal pace, and sat back down with their back against the backrest. The stopwatch was started at the initiation of movement and stopped when the participant had returned to the seat and their back was against the backrest. The TUG was performed twice, and the average of the two trials was used for analysis. The TUG has been shown to be strongly associated with balance (Podsiadlo and Richardson 1991) and predictive of fall risk (Shumway-Cook et al. 2000) in older adults.

Short physical performance battery The SPPB is a performance test assessing lower extremity function using measures of gait speed, standing balance, and chair rise performance. Volunteers were evaluated for their ability to balance during three different balance tests, a side-by-side stance, a semi-tandem stance, and a full-tandem stance. To assess gait speed, participants were timed from a standing start and asked to walk at their normal pace over a 4-m course. The faster of two trials was used. To assess lower extremity strength, volunteers were asked to cross their arms in front of their chest and rise from a chair as quickly as they could five times. Each test was scored on a 0–4-point scale. If the participant was unable to perform any of the tests, they received a score of zero. Scores of one to four were based on the time (in quartiles) necessary to complete the walk and chair rise tests and categories of performance in the balance tests (Guralnik et al. 1994). A summary performance score of 0–12 was then obtained by summing the scores of the three tests. SPPB was performed once during the baseline period. Scores obtained using the SPPB have been shown to be predictive of subsequent disability, institutionalization, and mortality (Guralnik et al. 1994, 2000).

Statistical analysis

Descriptive statistics were calculated for all variables. Intraclass correlations (ICC) were calculated to determine the reliability of the functional outcome and muscle performance measures at baseline. To evaluate baseline differences among groups in subject characteristics, a one-way ANOVA (for continuous variables) or Chi square [for categorical variables (sex)] was run. Mean differences for continuous variables were compared using a Sidak post hoc test. Change scores (post-training measure minus baseline measure) were calculated for habitual GS, maximal GS, TUG, SPPB and 1RM and compared between HSPT and CON (Analysis 1) and HI-V, LO-V and CON (Analysis 2). In both analyses, a univariate analysis of covariance (ANCOVA) was run on each change score adjusting for baseline functional score. Because variables such as age, sex, BMI, GDS, MMSE and MEDS have the potential to influence functional outcome and muscle performance measures in older adults, associations among variables were evaluated using Pearson's r. When associations with functional outcome or muscle performance measures were found ($p < 0.10$), those variables were used as covariates in all univariate tests. To test equality of variance of each dependent variable across treatment groups, Levene's test was used. Estimated marginal means from univariate tests were calculated from all ANCOVA models and compared using a Sidak post hoc test. Statistical significance for all models was accepted at $p < 0.05$.

Table 1 Baseline demographic and functional performance data

	HSPT ($n = 28$)	HI-V ($n = 14$)	LO-V ($n = 14$)	CON ($n = 14$)	p value‡
Age (years)	71.5 ± 6.8	68.4 ± 5.4	74.5 ± 7.0	71.1 ± 6.1	0.86/0.05*
Sex	11 Male, 17 female	7 Male, 7 female	4 Male, 10 female	5 Male, 9 female	0.82/0.49
BMI	27.7 ± 5.5	26.5 ± 3.8	28.7 ± 6.8	28.3 ± 5.9	0.34/0.39
MMSE	28.4 ± 1.5	28.6 ± 1.5	28.1 ± 1.4	28.4 ± 0.96	0.99/0.62
GDS	4.9 ± 4.1	3.7 ± 2.5	5.8 ± 4.9	5.4 ± 4.0	0.69/0.41
Meds (No.)	5.2 ± 4.2	4.9 ± 3.8	5.5 ± 4.6	5.2 ± 3.8	0.99/0.94
Habitual GS (m/s)	1.18 ± 0.21	1.21 ± 0.23	1.15 ± 0.28	1.10 ± 0.18	0.23/0.23
Maximal GS (m/s)	1.63 ± 0.30	1.72 ± 0.31	1.54 ± 0.28	1.57 ± 0.30	0.51/0.48
TUG (s)	9.6 ± 1.4	9.2 ± 1.4	9.9 ± 1.3	9.6 ± 1.9	0.94/0.40
SPPB (0–12)	9.2 ± 1.7	10.1 ± 1.1	8.4 ± 1.7	9.5 ± 1.2	0.52/0.01*
1RM (N)	1497.4 ± 442	1622 ± 406	1372 ± 455	1368.9 ± 396	0.36/0.20

All data present mean ± SD

HSPT high-speed power training, *HI-V* high-velocity training group (>0.88 m/s), *LO-V* low-velocity training group (<0.88 m/s), *CON* control group, *BMI* body mass index, *MMSE* mini-mental state examination, *GDS* geriatric depression scale, *Meds* number of current medications, *GS* gait speed, *TUG* timed up-and-go, *SPPB* short physical performance battery, *1RM* one-repetition maximum

‡ Multiple p values represent comparison of HSPT and CON (Experiment 1) and HI-V, LO-V, and CON (Experiment 2), respectively

* Significant group difference ($p < 0.05$)

Results

Reliability of functional outcome and muscle performance measures utilized in both analyses were outstanding based on the criteria established by Fleiss (1986): habitual GS (ICC: $R = 0.99$), maximal GS (ICC: $R = 0.97$), TUG (ICC: $R = 0.97$), and 1RM (ICC: $R = 0.96$). In both analyses, age and sex were associated with all functional outcomes and muscle performance measures ($p < 0.10$) and were used as adjustment variables in all statistical models. BMI, MMSE, and GDS also demonstrated associations with certain functional outcome and muscle performance measures ($p < 0.10$) and were used as adjustment variables in corresponding models.

Analysis 1

Baseline Demographic characteristics of HSPT and CON are presented in Table 1. There were no differences in any of the demographic variables among groups at baseline (all $p > 0.05$, see Table 1). There were no differences in baseline habitual or maximal GS, TUG, SPPB or 1RM between HSPT and CON (all $p > 0.05$; see Table 1).

Baseline to post-training Levene's test showed that the error variances for habitual GS ($p = 0.68$), maximal GS ($p = 0.34$), TUG ($p = 0.70$), SPPB ($p = 0.40$) and 1RM ($p = 0.61$) were equal across groups. Change scores for functional outcome measures are presented in Table 2. ANCOVA models showed no group differences in the change in habitual GS ($p = 0.60$), maximal GS ($p = 0.22$), or TUG ($p = 0.61$) between HSPT and CON. The change in SPPB was greater in HSPT compared to CON ($p = 0.01$). The change in 1RM was greater in HSPT compared to CON (303 ± 38 vs. 68 ± 51 N; $p = 0.001$).

Analysis 2

Baseline Demographic characteristics of HI-V, LO-V, and CON are presented in Table 1. Age was the only demographic variable that was different among groups at baseline ($p = 0.05$), with LO-V older than HI-V ($p = 0.04$) but not CON ($p = 0.60$). There were no significant differences in baseline habitual or maximal GS, TUG or 1RM among HI-V, LO-V and CON (all $p > 0.05$; see Table 1). SPPB was different among groups at baseline ($p = 0.01$), with SPPB higher in HI-V compared to LO-V ($p = 0.01$), but not CON ($p = 0.12$).

12-week HSPT intervention The median average velocity calculated from the 84,672 repetitions (to determine group allocation) was 0.88 m/s. Lower limb AV was higher for HI-V (1.0 ± 0.08 m/s) compared with LO-V (0.75 ± 0.09 m/s) ($p < 0.001$).

Baseline to post-training Levene's test showed that the error variances for habitual GS ($p = 0.61$), maximal GS ($p = 0.49$), TUG ($p = 0.41$), SPPB ($p = 0.16$) and 1RM ($p = 0.59$) were equal across groups. Change scores for functional outcome measures are presented in Table 2. ANCOVA models showed no group differences in the change in habitual GS ($p = 0.33$) among HI-V, LO-V and CON. ANCOVA models did show significant group differences in the change in maximal GS ($p = 0.007$), TUG ($p = 0.03$), SPPB ($p = 0.03$) and 1RM ($p = 0.005$). The

Table 2 Change scores in functional outcome measures and muscle performance

Experiment 1	HSPT ($n = 28$)		CON ($n = 14$)	*P* value
Habitual GS (m/s)	0.03 ± 0.16		0.03 ± 0.08	0.60
Maximal GS (m/s)	−0.02 ± 0.17		−0.06 ± 0.10	0.22
TUG (s)	−0.50 ± 1.23		−0.13 ± 1.14	0.61
SPPB (0–12)	1.04 ± 0.19		0.00 ± 0.82	0.01*
Experiment 2	**HI-V ($n = 14$)**	**LO-V ($n = 14$)**	**CON ($n = 14$)**	
Habitual GS (m/s)	0.06 ± 0.11	−0.01 ± 0.19	0.03 ± 0.08	0.33
Maximal GS (m/s)	0.04 ± 0.18	−0.07 ± 0.15	−0.06 ± 0.10	0.007*
TUG (s)	−0.84 ± 0.87	−0.18 ± 144	−0.13 ± 0.84	0.03*
SPPB (0–12)	1.2 ± 1.59	0.80 ± 0.92	0.00 ± 0.82	0.03*

All data represent mean ± SE

HSPT high-speed power training, *HI-V* high-velocity training group (>0.88 m/s), *LO-V* low-velocity training group (<0.88 m/s), *CON* control group, *GS* gait speed, *TUG* timed up-and-go, *SPPB* short physical performance battery

* Significant group difference ($p < 0.05$)

change in maximal GS was greater in HI-V compared to LO-V ($p = 0.01$) and CON ($p = 0.03$). The change in TUG was greater in HI-V compared to LO-V ($p = 0.03$), but not CON ($p = 0.27$). The change in SPPB was greater in HI-V compared to CON ($p = 0.02$), but not LO-V ($p = 0.34$). The change in 1RM was greater in HI-V compared to CON (308 ± 53 vs 66 ± 49 N; $p = 0.008$), but not LO-V (308 ± 53 vs 253 ± 59 N; p = 0.89). The change in 1RM was greater in LO-V compared to CON (253 ± 59 vs. 66 ± 49 N; $p = 0.05$).

Discussion

The major findings of this study were that the velocity generated during HSPT plays a critical role in whether this type of RT protocol significantly improves functional outcomes. When changes in function were compared between all participants of HSPT ($n = 28$) and CON in Analysis 1, only one of four functional measures showed improvement with training, similar to what has been observed in the literature (Caserotti 2010; Sayers et al. 2012). When changes in function were compared in the group with either the greatest lower limb AV (HI-V) compared with the group with the least lower limb AV (LO-V) or CON in Analysis 2, three of four functional measures showed significant improvement in those with the highest lower limb training velocity. Because of the variable nature of self-selected maximal limb velocity during HSPT in older adults, generating sufficient velocity is clearly paramount to functional performance. These data identify that for the present cohort of older adults, an AV of 0.88 m/s was necessary to ensure optimal improvement in functional performance for older adults taking part in HSPT; however, this threshold will need to be investigated further.

It is commonly thought that resistance training in any form is a certain remedy for functional improvement; however, systematic reviews and meta-analyses have reported only small to moderate effects on only certain functional tasks (Keysor and Jette 2001; Latham et al. 2004). Similarly, meta-analyses on a small number of power training studies to date show that, compared to strength training, there appears to be small to moderate improvements that are limited to primarily the types of tasks that emphasize movement speed (e.g., chair rise and stair climb), with little impact on gait-related tasks (Steib et al. 2010; Tschopp et al. 2011). What may be most interesting, given these findings, is that many power training regimens have not shown improvements in function even when compared to a non-resistance trained control group. We recently reported no improvements in 400-m walk, Berg Balance Scale, time chair rise or self-reported function after 12 weeks of HSPT compared to control in older adults with knee osteoarthritis (Sayers et al. 2012). Henwood et al. (2008) showed improvement in only 3 of 8 functional measures compared to control using a power training protocol with varying resistances (45, 60 and 75 % 1RM, while Caserotti (2010) found improvement in only half (50 %) and less than half (25 %) of the functional tasks when comparing explosive heavy-resistance power training to control in those 80+ years of age and 60+ years of age, respectively.

The lack of training effect in these studies could be related to the inclusion of more highly functioning older adults closer to their functional threshold (Buchner et al. 1996). The functional threshold theory suggests that there is a curvilinear relationship between changes in muscle strength and changes in function after RT, such that functionally limited adults with increases in muscle strength may observe large changes in function. Conversely, for healthier older adults similar improvements in muscle strength will likely result in very little change in function. Thus, differences in the number of functional tests that saw improvement between older participants (50 %) vs younger participants (25 %) in the Caserotti (2010) study could simply be because the older group was less highly functioning, farther from their functional threshold.

The positive transfer to task performance is likely maximized when specific muscle activation patterns reinforced through training are those that are required by the functional task (Barry and Carson 2004). Several authors have found that explosive forms of resistance training result in improved strength and power due to neural adaptations as opposed to muscle hypertrophy (Hakkinen et al. 1998; Reid et al. 2015). These adaptations could include increases in recruitment of active motor units or increases in firing rate, leading to improved activation of the agonist as well as decreased co-activation of antagonist muscles (Hakkinen et al. 1998). This increase in coordination among groups of muscle has been described as critical in the transfer of adaptation from resistance training to function in older adults (Barry and Carson 2004). Thus, higher speed power training may be increasing the coordination among groups of muscles to help the transfer of this training to task performance. It is interesting to note that none of the experimental conditions in the present study resulted in improvement in habitual GS. This may be because the specific muscle adaptation with HSPT (muscle power, peak velocity, movement speed) (Sayers and Gibson 2010, 2012, 2014; Sayers et al. 2012) are not the predominant muscle performance variable involved in this functional task. Maximal GS, on the other hand, might be expected to change with HSPT because the neural adaptations to the training demonstrate greater transfer to a maximal capacity speed test. However, the only improvement that was observed was in HI-V in Analysis 2, underscoring the importance of maximal lower limb training velocity to induce these neural adaptations.

Other power training studies using lower external resistances (20–40 %) and high movement speeds (Orr et al. 2006; Piirainen et al. 2014) have observed improvements in measures of balance. In Analysis 2, we observed improvements in TUG and SPPB, both of which have a static or dynamic balance component to the task despite also having a normal walking speed component. Perhaps lower limb AV in the HI-V group was of sufficient magnitude to improve balance just enough in these tests compared to the LO-V and confer significant functional improvement. Furthermore, greater lower limb AV would likely also preferentially confer the transfer of speed to improve the chair rise component of the TUG and SPPB observed in HI-V. While SPPB was shown to improve with HSPT (including those with lower limb AV below the median) in Analysis 1 compared to CON, improvement was clearly driven by those in the HSPT group that generated the greatest lower limb AV. This is evident by the fact that there was a difference in SPPB between HI-V and CON, but no difference between LO-V and CON.

One limitation of the study was that there were differences in age and SPPB found in the HI-V group compared to LO-V at baseline. It might be tempting to speculate that because the LO-V was older and had a lower SPPB at baseline, functional improvements favoring the HI-V group might occur in Analysis 2. First, we believe our ANCOVA models accounted for these differences statistically. Second, studies suggest that the greatest changes in function after RT exercise usually occur in more functionally limited adults who are below the functional threshold (Buchner et al. 1996). Thus, being older with a lower SPPB score would position the LO-V group to experience greater functional improvements compared to the HI-V group, but this did not occur. In fact, it is more likely that our HI-V and LO-V groups were both in a high-functioning older adult category based on their muscle strength and gait speed values (Fritz and Lusardi 2010; Lusardi 2003; Middleton et al. 2015), which were not different between groups. In addition, even though functional improvement is typically not seen after training in such high-functioning older adults who are closer to their functional threshold, significant improvement was found in 3 of the 4 functional outcome measures in the HI-V group who generated the greatest lower limb training velocity.

Another limitation of the study may be how to address potential remedies for those with lower limb AV below 0.88 m/s. How can we ensure that older adults participating in HSPT are providing a sufficient stimulus to the muscle if their self-selected movement velocity ("as fast as possible") is below this critical value? We believe that to actually monitor speed of movement during the training sessions and verbally encourage those to move the weight even faster when speeds fall below critical values could potentially help achieve the desired training effects of HSPT. This study and others over the previous decade in our laboratory (Sayers 2007; Sayers and Gibson 2010, 2012, 2014; Sayers et al. 2012) have only used verbal encouragement but no actual lower limb AV data during training to ensure the highest speed movements were being achieved. Now, knowledge of the actual lower limb AV data during a set of exercise can provide a quantitative assessment of movement speed to allow the practitioner to maximize the beneficial effects of HSPT. However, this may require a lowering of the external resistance early in the intervention to ensure adaptation to the necessary speed component of the training and gradually increase the resistance when the desired lower limb movement speeds are achieved. Adapting the training load based on velocity should not be viewed as detrimental to the training. This is a principle behind velocity-based training in young athletes as fluctuations in muscle performance due to life stressors (physical or mental) typically occur throughout a training cycle (Mann et al. 2015) and require sometimes daily adjustment. While decisions regarding load selection may result in a reduction in load on any given day, the maintenance of velocity within a specific range is the key to continued improvement and adaptation (Mann et al. 2015).

In younger athletes, the exploration of velocity-based resistance training and improved performance has been well studied. It has been shown that resistance training with bar velocities within the range of 0.75–1.0 m/s appear to confer performance benefits when the movement of heavier loads are critical (Jandacka and Beremlijski 2011; Jidovtseff et al. 2009; Roman 1986); for example, a lineman attempting to accelerate against the inertia of the external load of an opposing lineman (Mann et al. 2015). Conversely, resistance training with bar velocities within the range of 1.0–1.5 m/s will optimize performance that is dependent on more explosive aspects of strength (Jandacka and Beremlijski 2011; Jidovtseff et al. 2009; Roman 1986; Siff 2000), such as a football player exploding off the line of scrimmage (Mann et al. 2015). Thus, resistance training velocity "windows" have been examined and identified in younger athletes. Future research will have to determine whether different resistance training velocities result in preferential improvement in certain functional tasks in older adults as well as whether there are potentially resistance training velocities that represent a ceiling, above which functional adaptations are lost. With the older adult cohort in the present study, we can only say that at a particular % 1RM, there appears to be an AV floor of 0.88 m/s above which we see improved performance.

In conclusion, our results showed that simply engaging in HSPT may not be enough to definitively confer functional adaptations. There appears to be a threshold training velocity above which improvements in function are more likely. While we propose 0.88 m/s as the optimal training velocity in this cohort to see functional improvements, this threshold will require further study. In addition, it is important to emphasize that this recommended velocity is specific to explosive HSPT at low external resistances (40 % 1RM) and may not apply to power training at higher external resistances. However, our data show that higher training velocities do maximize functional performance benefits and may very well do the same at all external resistances. Future studies should examine differences in contraction velocity at moderate and heavy external resistances to determine its potential impact on an expanded number of functional outcome measures.

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Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Conflict of interest The authors declare that they have no conflicts of interest.

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