A Comparison of High-Speed Power Training and Traditional Slow-Speed Resistance Training in Older Men and Women

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Abstract

Sayers, SP and Gibson, K. A comparison of high-speed power training and traditional slow-speed resistance training in older men and women. *J Strength Cond Res* 24(12): 3369–3380, 2010—Muscle power, the product of force × velocity, is a critical determinant of function in older adults. Resistance training (RT) at high speed has been shown to improve peak muscle power in this population; however, different functional tasks may benefit from the improvement of power at values other than "peak" values, for example, tasks that require a greater velocity component or a greater force component. This study compared the effect of high-speed RT on muscle performance (peak power [PP] and its components [PP force and PP velocity] and overall peak velocity [VEL]) across a broad range of external resistances. Thirty-eight older men and women were randomized to high-speed power training at 40% of the 1-repetition maximum (1RM) (n = 13 [74.1 ± 6.4 years]); traditional RT at 80% 1RM (n = 13 [70.1 ± 7.0 years]); or control (n = 12 [72.8 ± 4.1 years]). Measures of muscle performance were obtained at baseline and after the 12-week training intervention. Muscle power and 1RM strength improved similarly with both high-speed and traditional slow-speed RT. However, speed-related muscle performance characteristics, PP velocity and overall VEL, were most positively impacted by high-speed power training, especially at lower external resistances. Because gains in speed-related measures with high-speed training compared to traditional RT do not come at the expense of other muscle performance outcomes, we recommend using an RT protocol in older adults that emphasizes high-speed movements at low external resistances.

Key Words muscle power, velocity, resistance training, aging

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Introduction

An inevitable consequence of aging is loss of muscle mass and concomitant reductions in muscle strength and functional capacity (22). One way to increase muscle strength is through resistance training (RT), and numerous studies have described the success of this method in older adults (10,13,24,28,32,35,37). In the past 2 decades, however, muscle power has emerged as a critical muscle performance characteristic in this population (3,5,9,12,36). Muscle power is the product of force × velocity and reflects the ability of the muscle to produce force rapidly (3). Decreases in muscle mass (22) and changes in the ability of the muscle to contract at high speed (such as type II muscle fiber loss and atrophy [19,20]; slowing of contractile velocity [17,18]; and slowing of nerve conduction velocity [29,38]) may accelerate the age-related decreases in power compared to strength. As a result, muscle power begins to decline sooner and more rapidly than muscle strength with aging (25) and at up to twice the rate than strength (3–4 vs. 1–2%) after age 60 (31).

A number of studies in the older adult literature have demonstrated that muscle power is a more critical variable to functional decline in older adults than muscle strength (3,5,12,36). Other studies have demonstrated that high-speed power training in older adults may also improve muscle power (11,15,23,27) or functional performance (26) compared to traditional RT with a strengthening component. A key outcome variable in these studies has been peak power (PP). This outcome measure has traditionally been determined by measuring power output at several percentages of the 1-repetition maximum (1RM) (3,6–8,11,30,33), and choosing the highest power output value across that range of external resistances. Power typically increases as external resistance is increased (see Figure 1) and decreases at the highest external resistances (11,33). The PP has typically been found at or near 70% 1RM in this population (11).

The PP, however, is not the only muscle power outcome variable that is valuable as a contributor to muscle performance. We reported previously that muscle power developed at high velocity (40% 1RM) and the corresponding contraction velocity at which that power was developed were better

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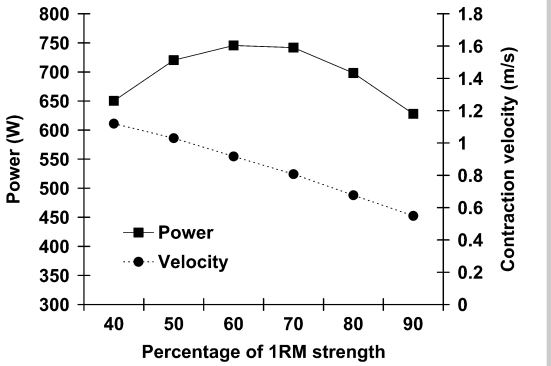


Figure 1. Data representing a power curve at baseline for the 38 older men and women in the study. Solid squares (■) represent peak muscle power and solid circles (●) represent peak velocity obtained across a range of external resistance (40–90% of the 1-repetition maximum [1RM]).

indicators of functional declines in older adults than muscle strength (1RM) or muscle power at slower velocities (70% 1RM) (34). These findings suggest that even if power output is similar at certain points along a power curve, the different velocities at which power is obtained could be a key factor in functional responses. For example, Figure 1 shows similar muscle power outputs obtained at both 40% 1RM and 90% 1RM; however, the velocity at which these power outputs was developed was very different, with power developed at 40% 1RM requiring a greater velocity component and power at 90% 1RM requiring a greater force component. Certain functional tasks may require power with a greater velocity component, whereas others may require power with a greater force component. This makes intuitive sense when one considers the different functional tasks that older adults encounter each day (e.g., moving the lower limb quickly to keep from falling vs. slowly getting up from a chair). Few studies in older adults have focused on the components of muscle power (such as force at PP or velocity at peak power [PPV]) and how these variables are impacted by RT.

We believe studies in this area have been limited by little or no examination of the following: (a) muscle power at values other than the "peak" value across a range of external resistances and (b) changes in muscle performance (power and its components [force and velocity] and overall peak velocity [VEL]) with RT. In addition, few studies have evaluated muscle performance variables relative to both the posttraining 1RM and baseline 1RM (which may be more applicable to real world situations where external resistances are fixed and not variable). The purpose of the study was to determine whether low-load, high-speed power training and traditional high-load, slow-speed RT may have differing effects on power output obtained across a range of external resistances. In addition, we sought to explore the impact of these RT regimens on the determinants of muscle power, that is, velocity and force at PP, and VEL; variables that could be critical to functioning but not commonly reported. We hypothesized that high-speed power training would improve muscle power to a greater extent than slow-speed RT through its effects on speed-related muscle performance characteristics (PPV and overall VEL).

Methods

Experimental Approach to the Problem

The goal of this study was to compare 12 weeks of explosive high-speed power training vs. traditional slow-speed RT with a strengthening component in older men and women and examine the effects of this training on muscle performance characteristics. Dependent variables in the study consisted of PP and its components (PPV and force at PP) and VEL across a range of external resistances (40–90% of the 1RM).

Table 1. Subject characteristics.*†

	HSPT (n = 13: 6m, 7f)	STR (n = 13: 5m, 8f)	CON (n = 12: 3m, 9f)	p
Age	74.1 ± 6.4	70.1 ± 7.0	72.8 ± 4.1	0.38
Height (cm)	170.3 ± 9.8	169.5 ± 10.6	165.8 ± 9.5	0.49
Weight (kg)	76.6 ± 18.5	71.0 ± 25.4	78.6 ± 17.7	0.66
GDS (0–30)	4.2 ± 5.0	6.7 ± 4.8	5.3 ± 3.9	0.40
MMSE (0–30)	28.3 ± 1.6	28.2 ± 2.7	28.6 ± 1.0	0.85
Medications (no.)	5.6 ± 2.6	4.5 ± 3.1	6.0 ± 3.2	0.45
Falls in the past year (no.)	0.15 ± 0.4	0.54 ± 0.8	0.17 ± 0.6	0.20

*HSPT = high-speed power training group; STR = slow-speed resistance training group; CON = control group; GDS = geriatric Depression Scale; MMSE = mini-mental state examination.
†Data are mean ± *SD*.

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Table 2. Muscle performance variables across a range of external resistances at baseline and after 12 weeks of resistance training (using loads relative to posttraining 1RM).*

Variable		40% 1RM	50% 1RM	60% 1RM	70% 1RM	80% 1RM	90% 1RM
Peak power (W)	HSPT	Pre: 298.5 ± 136.2	Pre: 321.8 ± 133.2	Pre: 329.4 ± 137.9	Pre: 317.4 ± 139.7	Pre: 293.8 ± 136.1	Pre: 250.8 ± 140.3
		Post: 378.3 ± 145.9	Post: 416.1 ± 164.3	Post: 415.1 ± 161.2	Post: 380.0 ± 153.6	Post: 340.8 ± 140.6	Post: 273.7 ± 120.1
		% Change: 27	% Change: 29	% Change: 26	% Change: 20	% Change: 16	% Change: 9
	STR	Pre: 324.6 ± 154.3	Pre: 360.7 ± 183.5	Pre: 364.4 ± 184.1	Pre: 357.2 ± 189.0	Pre: 325.8 ± 175.3	Pre: 306.8 ± 157.1
		Post: 397.3 ± 169.6	Post: 417.1 ± 196.0	Post: 431.0 ± 196.1	Post: 415.6 ± 182.9	Post: 378.7 ± 176.8	Post: 320.3 ± 157.0
		% Change: 22	% Change: 16	% Change: 18	% Change: 16	% Change: 16	% Change: 4
	CON	Pre: 270.3 ± 137.1	Pre: 294.8 ± 148.4	Pre: 294.4 ± 145.8	Pre: 285.9 ± 140.6	Pre: 265.4 ± 126.0	Pre: 244.1 ± 120.6
		Post: 281.9 ± 142.1	Post: 297.8 ± 144.7	Post: 292.4 ± 145.2	Post: 279.3 ± 125.6	Post: 265.8 ± 118.4	Post: 222.5 ± 93.4
		% Change: 4	% Change: 1	% Change: 0	% Change: −2	% Change: 0	% Change: −9
Peak power torque (N·m)	HSPT	Pre: 69.4 ± 18.2	Pre: 84.7 ± 22.0	Pre: 99.0 ± 26.7	Pre: 113.4 ± 31.4	Pre: 127.1 ± 36.3	Pre: 139.5 ± 40.6
		Post: 84.2 ± 23.6	Post: 102.8 ± 30.2	Post: 120.9 ± 36.7	Post: 138.9 ± 42.5	Post: 154.1 ± 50.6	Post: 168.6 ± 52.7
		% Change: 21	% Change: 21	% Change: 22	% Change: 23	% Change: 21	% Change: 20
	STR	Pre: 66.7 ± 21.8	Pre: 81.2 ± 26.8	Pre: 95.0 ± 32.1	Pre: 108.6 ± 38.5	Pre: 121.2 ± 44.7	Pre: 134.6 ± 50.1
		Post: 88.8 ± 31.4	Post: 109.0 ± 38.6	Post: 126.7 ± 47.7	Post: 147.1 ± 56.2	Post: 165.5 ± 64.6	Post: 182.8 ± 70.1
		% Change: 33	% Change: 34	% Change: 33	% Change: 35	% Change: 37	% Change: 36
	CON	Pre: 60.2 ± 22.8	Pre: 73.2 ± 28.4	Pre: 85.1 ± 33.8	Pre: 97.2 ± 39.3	Pre: 107.7 ± 41.3	Pre: 115.8 ± 45.6
		Post: 64.3 ± 25.0	Post: 77.9 ± 31.7	Post: 91.0 ± 38.7	Post: 102.8 ± 41.6	Post: 115.0 ± 51.3	Post: 126.4 ± 55.0
		% Change: 6	% Change: 6	% Change: 7	% Change: 6	% Change: 7	% Change: 9
Peak power velocity ($N \cdot m \cdot s^{-1}$)	HSPT	Pre: 4.2 ± 0.9	Pre: 3.7 ± 0.8	Pre: 3.3 ± 0.7	Pre: 2.7 ± 0.7	Pre: 2.3 ± 0.7	Pre: 1.8 ± 0.7
		Post: 4.4 ± 0.8	Post: 4.0 ± 0.7	Post: 3.4 ± 0.6	Post: 2.7 ± 0.6	Post: 2.2 ± 0.6	Post: 1.6 ± 0.5
		% Change: 5	% Change: 7	% Change: 4	% Change: 0	% Change: −2	% Change: −7
	STR	Pre: 4.7 ± 0.9	Pre: 4.3 ± 0.9	Pre: 3.7 ± 0.8	Pre: 3.2 ± 0.7	Pre: 2.6 ± 0.5	Pre: 2.3 ± 0.6
		Post: 4.4 ± 0.7	Post: 3.7 ± 0.7	Post: 3.3 ± 0.5	Post: 2.8 ± 0.4	Post: 2.3 ± 0.5	Post: 1.8 ± 0.5
		% Change: −7	% Change: −13	% Change: −11	% Change: −11	% Change: −13	% Change: −22
	CON	Pre: 4.3 ± 0.6	Pre: 3.9 ± 0.6	Pre: 3.4 ± 0.5	Pre: 2.9 ± 0.5	Pre: 2.4 ± 0.5	Pre: 2.1 ± 0.5
		Post: 4.3 ± 0.6	Post: 3.8 ± 0.5	Post: 3.2 ± 0.5	Post: 2.7 ± 0.4	Post: 2.3 ± 0.3	Post: 1.8 ± 0.5
		% Change: −1	% Change: −4	% Change: −7	% Change: −8	% Change: −5	% Change: −14
Peak velocity ($N \cdot m \cdot s^{-1}$)	HSPT	Pre: 4.3 ± 0.9	Pre: 3.7 ± 0.9	Pre: 3.3 ± 0.8	Pre: 2.8 ± 0.7	Pre: 2.3 ± 0.7	Pre: 1.8 ± 0.7
		Post: 4.5 ± 0.8	Post: 4.1 ± 0.8	Post: 3.5 ± 0.6	Post: 2.7 ± 0.6	Post: 2.2 ± 0.6	Post: 1.6 ± 0.6
		% Change: 6	% Change: 8	% Change: 4	% Change: −4	% Change: −6	% Change: −11
	STR	Pre: 4.8 ± 0.9	Pre: 4.3 ± 0.9	Pre: 3.8 ± 0.8	Pre: 3.2 ± 0.7	Pre: 2.7 ± 0.5	Pre: 2.3 ± 0.6
		Post: 4.4 ± 0.7	Post: 3.8 ± 0.8	Post: 3.4 ± 0.5	Post: 2.8 ± 0.4	Post: 2.3 ± 0.5	Post: 1.8 ± 0.5
		% Change: −7	% Change: −13	% Change: −11	% Change: −12	% Change: −13	% Change: −23
	CON	Pre: 4.4 ± 0.7	Pre: 4.0 ± 0.6	Pre: 3.4 ± 0.6	Pre: 3.0 ± 0.5	Pre: 2.5 ± 0.5	Pre: 2.1 ± 0.6
		Post: 4.3 ± 0.6	Post: 3.8 ± 0.5	Post: 3.2 ± 0.5	Post: 2.7 ± 0.4	Post: 2.4 ± 0.3	Post: 1.8 ± 0.5
		% Change: −1	% Change: −4	% Change: −7	% Change: −8	% Change: −6	% Change: −15

*HSPT = high-speed power training group; STR = slow-speed resistance training group; CON = control group.

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TABLE 3. Muscle performance variables across a range of external resistances at baseline and after 12 weeks of resistance training (using loads relative to baseline 1RM).*

Variable		40% 1RM	50% 1RM	60% 1RM	70% 1RM	80% 1RM	90% 1RM
Peak power (W)	HSPT	Pre: 313.2 ± 118.4 Post: 383.3 ± 113.3 % Change: 22	Pre: 339.0 ± 138.1 Post: 426.6 ± 133.6 % Change: 25	Pre: 350.6 ± 144.1 Post: 456.6 ± 136.6 % Change: 30	Pre: 342.8 ± 149.6 Post: 456.3 ± 150.2 % Change: 33	Pre: 317.2 ± 145.6 Post: 457.6 ± 149.3 % Change: 44	Pre: 272.9 ± 154.2 Post: 431.3 ± 162.4 % Change: 58
	STR	Pre: 331.5 ± 163.9 Post: 380.3 ± 204.9 % Change: 15	Pre: 366.7 ± 198.0 Post: 421.2 ± 230.3 % Change: 15	Pre: 371.7 ± 197.2 Post: 443.9 ± 237.9 % Change: 19	Pre: 365.1 ± 203.4 Post: 465.2 ± 252.1 % Change: 27	Pre: 333.0 ± 189.5 Post: 467.5 ± 244.5 % Change: 40	Pre: 319.2 ± 167.0 Post: 444.6 ± 243.8 % Change: 39
	CON	Pre: 292.6 ± 165.9 Post: 283.5 ± 153.9 % Change: −3	Pre: 315.5 ± 180.0 Post: 313.9 ± 169.1 % Change: 0	Pre: 315.4 ± 178.8 Post: 327.3 ± 180.0 % Change: 4	Pre: 304.4 ± 174.3 Post: 320.3 ± 180.5 % Change: 5	Pre: 281.4 ± 155.3 Post: 302.9 ± 169.7 % Change: 8	Pre: 252.1 ± 150.7 Post: 242.4 ± 111.2 % Change: −3
Peak power torque (N·m)	HSPT	Pre: 69.7 ± 18.0 Post: 73.4 ± 15.8 % Change: 5	Pre: 85.4 ± 21.8 Post: 89.6 ± 21.6 % Change: 5	Pre: 99.5 ± 25.9 Post: 104.6 ± 25.9 % Change: 5	Pre: 114.3 ± 31.2 Post: 121.5 ± 31.2 % Change: 6	Pre: 128.8 ± 35.9 Post: 135.9 ± 36.9 % Change: 6	Pre: 141.1 ± 42.3 Post: 152.8 ± 41.9 % Change: 8
	STR	Pre: 66.5 ± 23.8 Post: 72.1 ± 28.9 % Change: 8	Pre: 80.1 ± 29.2 Post: 87.5 ± 35.7 % Change: 8	Pre: 94.5 ± 35.0 Post: 102.3 ± 42.8 % Change: 8	Pre: 107.7 ± 42.0 Post: 117.7 ± 49.8 % Change: 9	Pre: 120.5 ± 48.7 Post: 132.5 ± 58.5 % Change: 10	Pre: 133.6 ± 54.6 Post: 145.6 ± 63.2 % Change: 8
	CON	Pre: 65.1 ± 26.6 Post: 66.6 ± 25.4 % Change: 2	Pre: 79.6 ± 33.2 Post: 81.3 ± 32.9 % Change: 2	Pre: 92.7 ± 39.5 Post: 95.1 ± 39.3 % Change: 3	Pre: 106.3 ± 46.6 Post: 108.4 ± 43.7 % Change: 2	Pre: 117.4 ± 48.2 Post: 120.2 ± 48.2 % Change: 2	Pre: 125.8 ± 53.8 Post: 130.7 ± 56.6 % Change: 4
Peak power velocity ($N \cdot m \cdot s^{-1}$)	HSPT	Pre: 4.4 ± 0.8 Post: 5.2 ± 0.6 % Change: 18	Pre: 3.9 ± 0.9 Post: 4.7 ± 0.6 % Change: 22	Pre: 3.5 ± 0.8 Post: 4.4 ± 0.5 % Change: 27	Pre: 2.9 ± 0.7 Post: 3.8 ± 0.5 % Change: 28	Pre: 2.4 ± 0.7 Post: 3.4 ± 0.5 % Change: 40	Pre: 1.9 ± 0.7 Post: 2.8 ± 0.5 % Change: 50
	STR	Pre: 4.8 ± 0.8 Post: 4.8 ± 1.5 % Change: −1	Pre: 4.3 ± 0.9 Post: 4.6 ± 0.8 % Change: 7	Pre: 3.8 ± 0.8 Post: 4.2 ± 0.7 % Change: 10	Pre: 3.2 ± 0.7 Post: 3.8 ± 0.6 % Change: 17	Pre: 2.7 ± 0.5 Post: 3.4 ± 0.6 % Change: 27	Pre: 2.4 ± 0.5 Post: 3.0 ± 0.6 % Change: 24
	CON	Pre: 4.3 ± 0.8 Post: 4.1 ± 0.6 % Change: −4	Pre: 3.8 ± 0.7 Post: 3.7 ± 0.5 % Change: −2	Pre: 3.3 ± 0.6 Post: 3.3 ± 0.5 % Change: 0	Pre: 2.8 ± 0.7 Post: 2.8 ± 0.5 % Change: 1	Pre: 2.4 ± 0.6 Post: 2.4 ± 0.5 % Change: 3	Pre: 2.0 ± 0.7 Post: 1.9 ± 0.4 % Change: −4
Peak velocity ($N \cdot m \cdot s^{-1}$)	HSPT	Pre: 4.5 ± 0.9 Post: 5.3 ± 0.9 % Change: 17	Pre: 3.9 ± 0.9 Post: 4.8 ± 0.6 % Change: 22	Pre: 3.5 ± 0.8 Post: 4.4 ± 0.6 % Change: 26	Pre: 3.0 ± 0.7 Post: 3.8 ± 0.5 % Change: 27	Pre: 2.5 ± 0.7 Post: 3.5 ± 0.5 % Change: 40	Pre: 1.9 ± 0.8 Post: 2.9 ± 0.5 % Change: 50
	STR	Pre: 4.9 ± 0.7 Post: 5.1 ± 0.9 % Change: 5	Pre: 4.4 ± 0.9 Post: 4.7 ± 0.8 % Change: 7	Pre: 3.9 ± 0.8 Post: 4.2 ± 0.7 % Change: 9	Pre: 3.3 ± 0.7 Post: 3.9 ± 0.6 % Change: 18	Pre: 2.8 ± 0.6 Post: 3.5 ± 0.6 % Change: 27	Pre: 2.5 ± 0.6 Post: 3.0 ± 0.6 % Change: 24
	CON	Pre: 4.3 ± 0.8 Post: 4.1 ± 0.6 % Change: −4	Pre: 3.9 ± 0.7 Post: 3.8 ± 0.5 % Change: −4	Pre: 3.3 ± 0.7 Post: 3.4 ± 0.5 % Change: −1	Pre: 2.9 ± 0.7 Post: 2.8 ± 0.4 % Change: −5	Pre: 2.4 ± 0.7 Post: 2.5 ± 0.5 % Change: 1	Pre: 2.0 ± 0.8 Post: 1.9 ± 0.4 % Change: −9

*HSPT = high-speed power training group; STR = slow-speed resistance training group; CON = control group.

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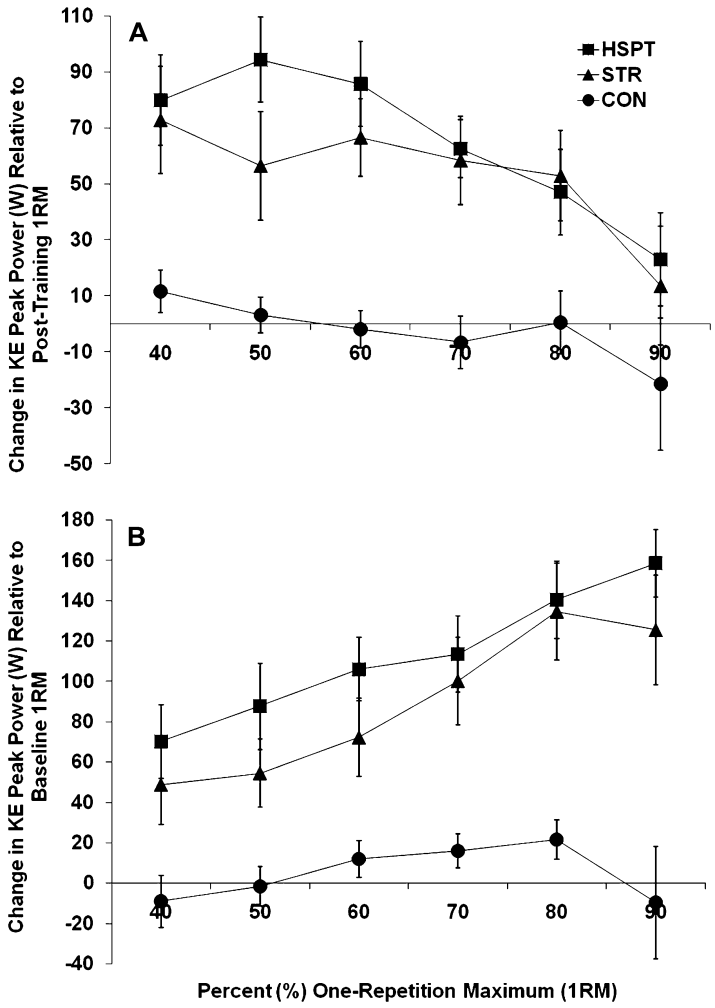


Figure 2. Change in knee extension peak power across a range of external resistances (40–90% of the 1-repetition maximum [1RM]) relative to A) posttraining 1RM and B) baseline 1RM for high-speed power training group (HSPT), traditional slow-speed resistance training group (STR), and control (CON). All data represent mean ± *SEM*.

Subjects

Fifty-two participants were originally enrolled in the study and randomized to 1 of 3 treatment arms: High-Speed Power Training at 40% 1RM (HSPT), Slow-Speed RT with a strengthening component at 80% 1RM (STR), or Control (CON). All participants were healthy by self-report and community-dwelling but possessed some limitations in either function or mobility. All participants were seen by a study physician before they were allowed to take part in the study. Exclusion criteria consisted of history of heart disease, osteoarthritis, 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 a structured exercise. Fourteen of the 52 enrolled study subjects discontinued participation in the study. Eleven dropped out of the study before they had begun their training: Eight could not find time in their schedules to participate, and 3 withdrew after being informed of their randomization into the control group. Of the 41 remaining participants who began the exercise study, our retention rate was excellent (93%). Only 3 participants withdrew during the intervention, 1 in each of the 3 groups. One participant in the HSPT group withdrew because of a recurring back injury (not study related), 1 in the STR group withdrew because of pain in her knee, and 1 in the CON group could no longer find transportation to and from the facility. This left 38 older men and women (HSPT: $n = 13$; STR: $n = 13$; CON: $n = 12$) 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

Maximal Strength and Power Determination. Leg press (LP) and seated knee extension (KE) 1RM were obtained using Keiser a420 pneumatic (air resistance) equipment (Fresno, CA, USA). Keiser's a420 computer-interfaced pneumatic RT equipment is designed to capture the measures of strength and additional muscle performance measures calculated with computer software. 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 measures of peak muscle power, PPV, force at PP, and VEL 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 the KE data from the study are presented here.

One repetition maximum measures were obtained by progressively increasing the resistance until the subject was

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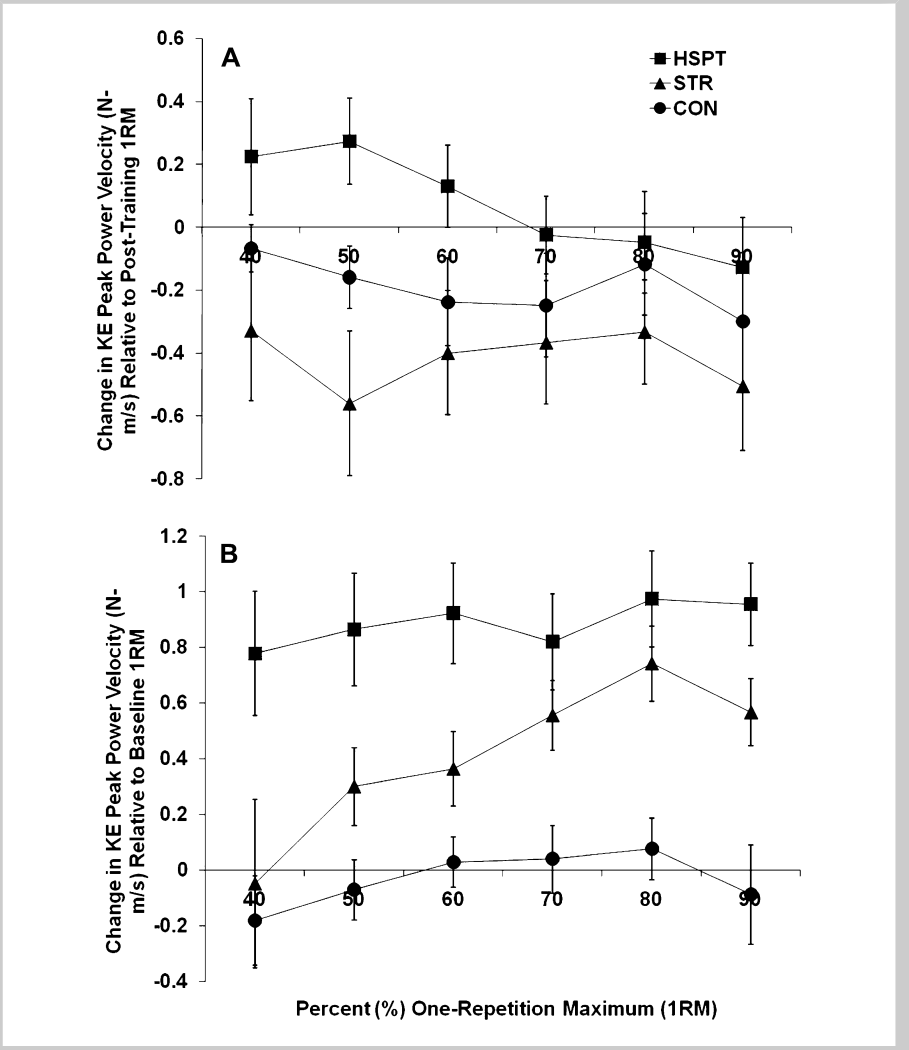


Figure 3. Change in knee extension peak power velocity across a range of external resistances (40–90% of the 1-repetition maximum [1RM]) relative to A) posttraining 1RM and B) baseline 1RM for high-speed power training group (HSPT), traditional slow-speed resistance training group (STR), and control (CON). All data represent mean ± *SEM*.

no longer able to push out 1 repetition successfully. The ratings of perceived exertion scale (4) was used to assist in evaluating when 1RM (combined with perceived maximal effort) was successfully reached. Peak muscle power was obtained at 40, 50, 60, 70, 80, and 90% of the 1RM approximately 30 minutes after the 1RM measure was obtained (7,30). Participants were instructed to exert "as fast as possible" at each of these relative percentages of the 1RM. Three attempts were made at each resistance, and the greatest PP output obtained at each resistance was used in the analysis. The PPV, the torque at peak power (PPT), and VEL were obtained for each external resistance across the power curve. The 1RM was measured every 2 weeks in the HSPT and STR groups only, and relative training intensity was adjusted accordingly to ensure adequate overload during the training period. All outcome measures of 1RM and power across a range of external resistances (40–90% 1RM) were performed twice during the baseline period to establish reliability and once at the end of the 12-week period. A second posttraining measure of muscle performance (PP, PPV, PPT, and VEL) across the range of external resistances (40–90% 1RM) was also obtained 1 week after the power test performed at 12 weeks. However, the loads used were relative to the initial baseline 1RM (not relative to the higher 1RM resulting from the training intervention). Because this second power test was introduced after the study had commenced, only 27 of the 38 participants underwent this final evaluation (HSPT: $n = 9$; STR: $n = 11$; CON: $n = 7$).

Resistance Training Protocol. Volunteers randomized into HSPT and STR groups exercised 3 times per week for 12 weeks using computer-interfaced Keiser a420 pneumatic LP and KE RT equipment. For HSPT, each training session consisted of 3 sets of 12–14 repetitions at 40% of the 1RM. Participants performed each movement at high velocity during the concentric phase of each repetition ("as fast as possible"), paused for 1 second, and performed the eccentric portion of the contraction over 2 seconds. Volunteers randomized into the STR group also exercised 3 times per week for 12 weeks using the same Keiser a420 RT equipment. For STR, each training session consisted of 3 sets of 8–10 repetitions at 80% of the 1RM. Repetitions were higher in the HSPT group to more closely equate work performed between the training groups and to remain consistent with RT exercise guidelines (1). The participants performed each movement at a slow velocity using proper technique (2 seconds for concentric phase of the repetition), paused for 1 second, and performed the eccentric portion of the contraction over over a 2-second duration. Thus, the key differences in the RT protocols between HSPT and STR was the percentage of the 1RM at which each group trained (40 vs.

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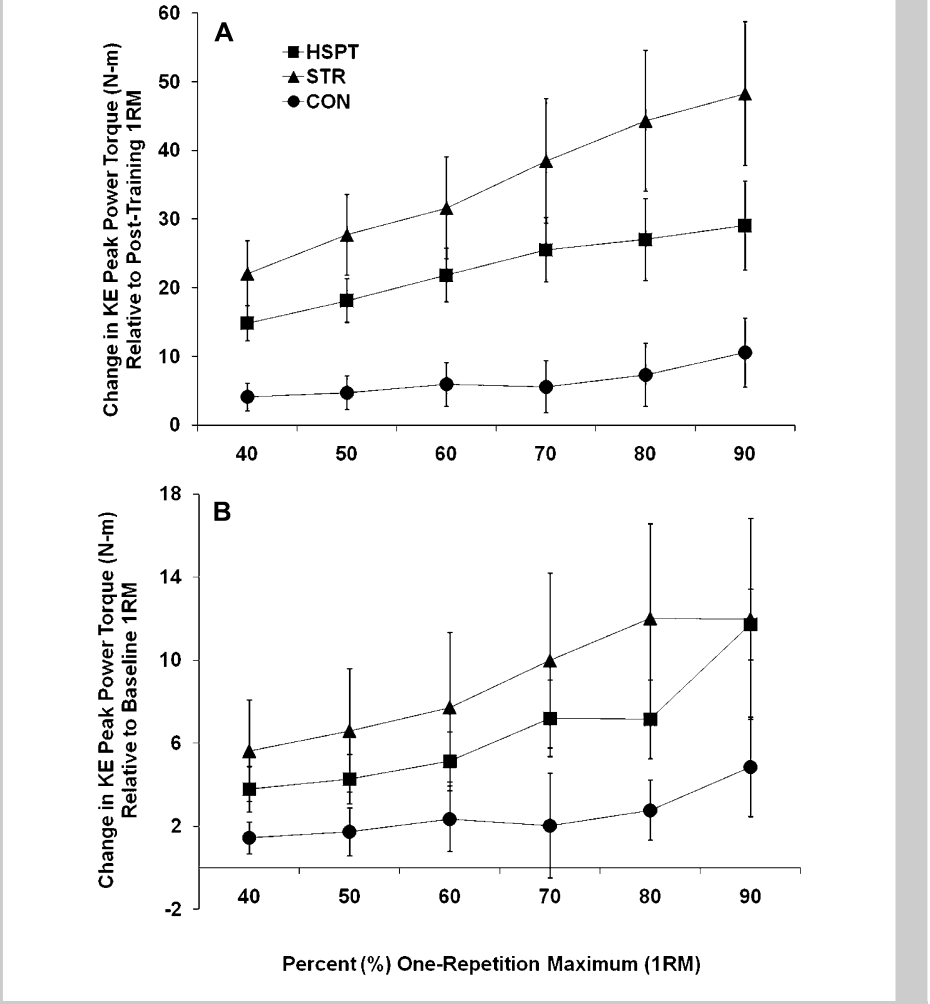


Figure 4. Change in knee extension peak power torque across a range of external resistances (40–90% of the 1-repetition maximum [1RM]) relative to A) posttraining 1RM and B) baseline 1RM for high-speed power training group (HSPT), traditional slow-speed resistance training group (STR), and control (CON). All data represent mean ± *SEM*.

80%) and the speed at which the weights were moved concentrically. The CON group met three times a week to participate in the warm-up and stretching exercises but performed no RT exercise. The HSPT and STR groups participated in the same warm-up and stretching exercises as the CON group did before their training.

Statistical Analyses

Descriptive statistics were run on all variables. One-way analysis of variance (ANOVA) was run to evaluate baseline differences among groups in subject characteristics and KE 1RM strength. To evaluate baseline differences among groups in muscle performance (PP, PPV, PPT, and VEL) across a range of external resistances, a 3 × 6 (group by condition [i.e., 40, 50, 60, 70, 80, 90% 1RM]) repeated measures ANOVA was run for each muscle performance measure. A 3 × 2 (group by time) repeated measures ANOVA was run to evaluate differences among groups in KE 1RM strength from baseline to posttesting. Change scores in PP, PPV, PPT, and VEL with training were obtained by subtracting the baseline values from the posttraining value. To evaluate differences among groups in the change in muscle performance across 6 external resistances with training, a 3 × 6 (group by condition) repeated-measures ANOVA was run for each muscle performance measure. When equal variances were not observed using Mauchley's test of sphericity, corrections to the *F*-ratio were applied using Greenhouse–Geyser Epsilon values. In statistically significant repeated measures ANOVA models (group main effects or group by time interactions), post hoc testing using Tukey's HSD (when main effects were present) or independent samples *t*-tests (when interactions were present) was performed to determine the source of statistically significant differences. Statistical significance for Chi-square tests (Mauchley), ANOVA models, and *t*-tests was accepted at $p \leq 0.05$. Data are reported as mean ± *SD*.

Results

Baseline Measures

There were no differences in age, height, weight, depressive symptoms, cognitive function, number of medications, or falls in the past year among groups at baseline (all $p > 0.05$; see Table 1). Knee extension 1RM strength among groups (HSPT:158 ± 56 N m; STR: 173 ± 66 N m; CON: 145 ± 62 N m was not different at baseline ($F = 0.62$; $p = 0.55$).

When comparing muscle performance characteristics of our 3 groups at baseline (HSPT: $n = 13$; STR: $n = 13$; CON: $n = 12$) during performance of a power test across a range of external resistances (40–90%1RM), we found no group main effects or group by condition interactions in PP (Group: $F = 0.60$; $p = 0.56$; G × C: $F = 0.57$; $p = 0.84$), PPV (Group: $F = 1.8$; $p = 0.18$; G × C: $F = 0.56$; $p = 0.85$), PPT (Group: $F = 0.72$; $p = 0.49$; G ×

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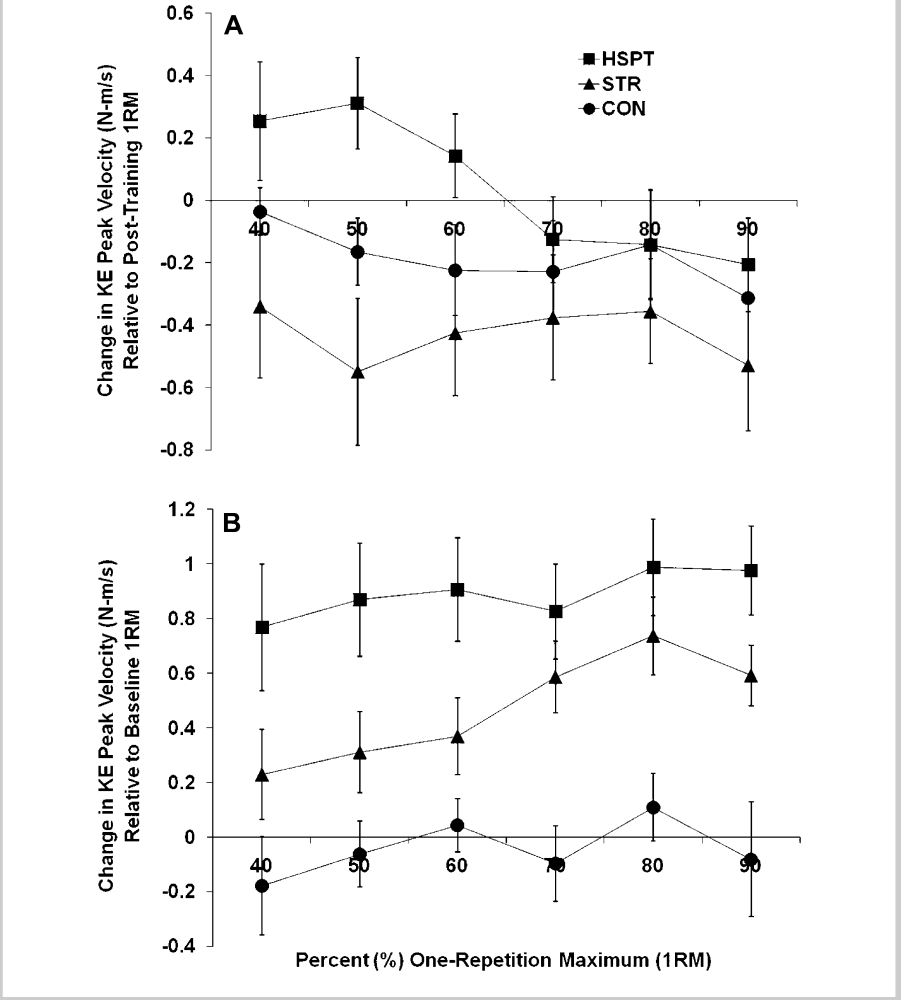


Figure 5. Change in knee extension peak velocity across a range of external resistances (40–90% of the 1-repetition maximum [1RM]) relative to A) posttraining 1RM and B) baseline 1RM for high-speed power training group (HSPT), traditional slow-speed resistance training group (STR), and control (CON). All data represent mean ± *SEM*.

C: $F = 1.1$; $p = 0.38$), or VEL (Group: $F = 1.7$; $p = 0.19$; G × C: $F = 0.51$; $p = 0.88$) among groups. Condition main effects for all muscle performance characteristics at baseline were all significant (all $p < 0.001$) as expected because of the parabolic nature of the power curve (Figure 1) and the decrease in velocity and increase in force typically observed across this range of increasing resistances (40–90% 1RM) (33).

Comparing the baseline muscle performance characteristics in a subset of participants in our 3 groups (HSPT: $n = 9$; STR: $n = 11$; CON: $n = 7$) during performance of a power test across a range of external resistances (40–90%1RM), we also found no differences in baseline PP (Group: $F = 0.23$; $p = 0.80$; G × C: $F = 0.41$; $p = 0.94$), PPV (Group: $F = 1.3$; $p = 0.30$; G × C: $F = 0.40$; $p = 0.95$), PPT (Group: $F = 0.12$; $p = 0.89$; G × C: $F = 0.30$; $p = 0.98$), or VEL (Group: $F = 1.2$; $p = 0.32$; G × C: $F = 0.36$; $p = 0.96$) among groups. Condition main effects for all muscle performance characteristics at baseline were significant (all $p < 0.001$) as expected.

Changes from Baseline

Differences among groups in KE 1RM strength were compared from baseline to posttraining. There was a significant time main effect, with KE 1RM strength increasing 19% over 12 weeks of training ($F = 27.9$; $p < 0.001$). There was no significant group main effect ($F = 1.8$; $p = 0.18$), but there was a significant group × time interaction ($F = 6.9$; $p = 0.003$) suggesting there was a difference in the pattern of response to the different training methods. The KE 1RM increased in the HSPT group (25%) compared to in the STR (26%) and CON (0%) groups.

The changes in PP, PPV, PPT, and VEL across a range of external resistances (40–90% 1RM) were compared from baseline to posttraining. The loads used to assess posttraining PP, PPV, PPT, and VEL were relative to (a) the final posttraining 1RM and (b) the baseline 1RM. Sample sizes for the latter evaluations (b) were as follows: HSPT ($n = 9$), STR ($n = 11$), CON ($n = 7$). The values for all of our baseline and posttraining PP, PPV, PPT, and VEL for all participants and the subset of participants can be seen in Tables 2 and 3, respectively.

Peak Power. In the first analysis (a), repeated-measures ANOVA using the change scores relative to the posttraining 1RM indicated a significant group main effect ($F = 12.5$; $p < 0.001$) and condition main effect ($F = 6.4$; $p < 0.001$) but no significant group by condition interaction ($F = 0.79$; $p = 0.64$) (see Figure 2A). To further evaluate the significant group main effect, post hoc testing revealed that both HSPT ($p < 0.001$) and STR ($p = 0.001$) demonstrated greater PP output compared to CON but were not significantly different from each other ($p = 0.68$). In the second analysis (b), repeated--measures ANOVA using change scores relative to the baseline 1RM indicated a significant group main effect ($F = 9.5$; $p = 0.001$), condition main effect ($F = 13.6$; $p < 0.001$)

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and group by condition interaction ($F = 2.7$; $p = 0.005$) (Figure 2B). To further evaluate the significant interaction, post hoc testing revealed that both HSPT and STR demonstrated greater PP output compared to CON at 40% 1RM (both: $p \leq 0.05$), 50% 1RM (both: $p \leq 0.02$), 60% 1RM (both: $p \leq 0.03$), 70% 1RM (both: $p \leq 0.001$), 80% 1RM (both: $p \leq 0.002$), and 90% 1RM (both: $p \leq 0.004$) but were not significantly different from each other at any time point (all: $p > 0.05$).

Velocity at Peak Power. In the first analysis (a), repeated-measures ANOVA using the change scores relative to the posttraining 1RM indicated a significant group main effect ($F = 4.2$; $p = 0.05$) and condition main effect ($F = 2.5$; $p = 0.03$) but no significant group by time interaction ($F = 1.4$; $p = 0.17$) (Figure 3A). To further evaluate the significant group main effect, post hoc testing revealed that HSPT demonstrated greater PPV compared to STR ($p = 0.03$) but not CON ($p = 0.23$). The STR and CON values were not significantly different from each other ($p = 0.30$). In the second analysis (b), repeated-measures ANOVA using the change scores relative to the baseline 1RM indicated a significant group main effect ($F = 11.8$; $p < 0.001$), condition main effect ($F = 3.3$; $p = 0.007$) but no group by condition interaction ($F = 1.1$; $p = 0.40$) (Figure 3B). To further evaluate the significant group main effect, post hoc testing revealed that HSPT demonstrated greater PPV compared to STR ($p = 0.03$) and CON ($p < 0.001$). The STR group did not demonstrate greater PPV compared to the CON group ($p = 0.06$) but showed a strong trend.

Torque (Force) at Peak Power. In the first analysis (a), repeated-measures ANOVA using the change scores relative to the posttraining 1RM indicated a significant group main effect ($F = 6.5$; $p = 0.004$), condition main effect ($F = 23$; $p < 0.001$), and group by condition interaction ($F = 3.7$; $p < 0.001$) (Figure 4A). To further evaluate the significant interaction, post hoc testing revealed that both HSPT and STR demonstrated greater PPT compared to CON at 40% 1RM (both: $p \leq 0.003$), 50% 1RM (both: $p \leq 0.003$), 60% 1RM (both: $p \leq 0.009$), 70% 1RM (both: $p \leq 0.004$), 80% 1RM (both: $p \leq 0.02$), and 90% 1RM (both: $p \leq 0.03$) but were not significantly different from each other at any time point (all: $p > 0.05$). In the second analysis (b), repeated-measures ANOVA using the change scores relative to the baseline 1RM indicated a significant main effect for condition ($F = 21$; $p = 0.001$) but no significant group main effect ($F = 1.2$; $p = 0.31$) or group by condition interaction ($F = 1.2$; $p = 0.32$) (Figure 4B).

Peak Velocity. In the first analysis (a), repeated-measures ANOVA using the change scores relative to the posttraining 1RM indicated no significant group main effect ($F = 2.3$; $p = 0.11$), but there was a significant condition main effect ($F = 6.1$; $p = 0.002$) and group by condition interaction ($F = 2.1$; $p = 0.02$) (Figure 5A). To further evaluate the significant interaction, post hoc testing revealed that HSPT demonstrated greater VEL compared to CON at 50% 1RM ($p = 0.02$) only but showed a strong trend at 60% 1RM ($p = 0.08$). The HSPT group demonstrated greater VEL compared to the STR group at 50% 1RM ($p = 0.005$) and 60% 1RM ($p = 0.03$) and showed a strong trend at 40% 1RM ($p = 0.06$). The HSPT and STR values were not different from the CON value at 70% 1RM (both: $p > 0.05$), 80% 1RM (both: $p > 0.05$), or 90% 1RM (both: $p > 0.05$). In the second analysis (b), repeated-measures ANOVA using the change scores relative to the baseline 1RM indicated a significant group main effect ($F = 11$; $p < 0.001$) and condition main effect ($F = 3.2$; $p = 0.009$) but no group by condition interaction ($F = 0.81$; $p = 0.62$) (Figure 5B). To further evaluate the significant group main effect, post hoc testing revealed that HSPT demonstrated greater VEL compared to STR ($p = 0.03$) and CON ($p < 0.001$). The STR group demonstrated greater VEL compared to the CON group ($p = 0.01$).

Discussion

Over the past 2 decades, muscle power has been examined extensively in the older adult population, both as a predictor of performance (3,5,34,36) and as an outcome variable in RT and power training studies (6–8,11,14–16,27). Previous studies on this topic have been limited by little or no examination of (a) muscle power at values other than the "peak" value across the full spectrum of the power curve and (b) changes in the different components of muscle power (force at PP and PPV) with RT. The present study addressed these 2 limitations by examining how 2 different RT protocols, 1 approach emphasizing high-speed movements at low resistance (high-speed power training) and the other approach emphasizing slow-speed movements at high resistance (traditional RT with a strengthening component), contribute to muscle performance (i.e., muscle power and its components [force at PP and PPV] and VEL) across a range of external resistances. In addition to focusing on changes in muscle performance relative to the posttraining 1RM, we also included an evaluation of changes in muscle performances relative to the baseline 1RM, which may be more applicable to real-world situations where external resistances are fixed and not variable. This investigation is one of the first to focus on how high-speed RT impacts muscle performance across a range of external resistances that might be encountered in daily task performance. Similar to previous studies, we found that muscle performance characteristics improved with both high-speed and traditional slow-speed RT. However, novel findings were that speed-related muscle performance characteristics, such as PPV and overall VEL, were most positively impacted by high-speed power training, especially at lower external resistances. In addition, there were similar increases in 1RM strength obtained with both high-speed power training and traditional RT; thus, the gains in speed-related measures with high-speed training compared to traditional RT do not come at the expense of other muscle performance outcomes.

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Since the earliest studies of muscle power in older adults, PP (the highest power value across the spectrum of the power curve) has been repeatedly shown to be a strong predictor of functional performance (2,3,12,36) and even more important than muscle strength (3,5,33,36). As a result, RT protocols for older adults were developed with the intention of improving peak muscle power. In 2004 and 2005, 2 studies reported that muscle power developed at high speeds (40% 1RM) and the corresponding VEL at that external resistance were stronger predictors of functional decline than power at 70% 1RM (a power value typical of PP values across the power curve) (5,34). These studies led us to believe that power values other than the typical "peak" value, and factors that contribute to power (i.e., velocity) may be important to focus on in RT studies. Although many studies have explored high-speed power training (6,11,14,16,21,26), to our knowledge, no studies have reported the impact of this type of training on power values across a range of external resistances. Two studies we are aware of have examined the force and velocity components of muscle power after power training (7,21); however, no studies to date have examined these components across a range of external resistances, at other than peak muscle power, and whether force at PP and PPV are differentially affected by different types of RT.

When comparing changes in muscle performance relative to the final posttraining 1RM, we found that both HSPT and STR increased PP across a range of external resistances compared to control; but, neither protocol was superior to the other. Thus in contrast to our initial hypothesis, PP can be improved similarly across a range of external resistances by performing high-velocity or slow-velocity training. Similarly, both HSPT and STR increased PPT at all power values across a range of external resistances compared to control, but again, neither protocol was superior to the other. These findings in our high-speed training group are in agreement with those of de Vos et al. (7), who reported that the force component of muscle power (at peak only) increased significantly during high-speed power training in 3 different training groups (20, 50, 80% 1RM).

When we compared the velocity components of muscle power with different training regimens, however, differences began to emerge between our training groups. HSPT did not increase PPV compared to CON, again in agreement with the findings of de Vos et al. (7) but did increase PPV in HSPT compared to STR. In addition, HSPT increased overall VEL compared to both STR and CON at the lowest external resistances, ranging from 40 to 60% of the 1RM. Thus, slow-speed training appeared to decrease speed-related components of muscle performance compared to high-speed training. If traditional RT results in an actual slowing of movement speed in older adults, and increased speed is a critical factor in function in this population (34), these findings could dramatically change the way we design and implement RT programs in older adults.

It has been argued that increases in the 1RM associated with RT could account for the apparent decrease in PPV after RT with a strengthening component (8). For example, the movement of heavier weights following gains in 1RM strength with an RT protocol would lead to the slowing of movement speed because of the force–velocity relationship. However, in this study, 1RM strength increases after 12 weeks of training were similar in both the high-speed and slow-speed training groups (~26% in both groups). This suggests that speed-related increases in muscle performance in the high-speed training group compared to the traditional RT were likely because of the differences in the speed of the training protocols, not differences in 1RM improvement between groups. Moreover, speed appears to be trainable in the older adult population. In addition, it may be misleading to simply state that PPV was not different between the high-speed training group and control, given that there was no increase in the 1RM in the control group over 12 weeks. Because the HSPT group significantly increased their 1RM compared to control (25 vs. 0%), these 2 groups were moving very different resistances when being tested at the same percentage of the 1RM.

Few studies on muscle power in older adults have compared changes in muscle power (and its components) relative to the baseline 1RM (8). This was done in this study to account for potential differences in the 1RM that could have occurred with the different training regimens. We initially hypothesized that training at a higher percent of the 1RM (80% 1RM) would improve 1RM strength to a greater degree than at a lower percentage of the 1RM (40% 1RM); however, this did not occur in this study. As previously discussed, the lack of reported change in velocity relative to the final 1RM after training (7) was largely because of training-induced increases in the 1RM; thus, speed-related changes may not be as profound given that a heavier weight is being moved (albeit at the same percentages of 1RM). In real-world situations, however, some external resistances are fixed and would not vary with functional performance. For example, the force necessary to depress a gas pedal in a car or rise from a chair does not change after training, so representing these tasks by having a person depress a "heavier" brake pedal or rise from a chair wearing a weighted vest would not reflect the actual force necessary to accomplish the task. This, in essence, is what we measure when we assess changes in muscle performance after training relative to the final posttraining 1RM. Thus, including evaluation of performance against a fixed external resistance (loads based upon the baseline 1RM) might better reflect how speed-related changes in muscle performance are applicable to real-world situations.

In this study, we found that changes in muscle performance across a range of external resistances produced at the same 1RM as that initially obtained at baseline were improved with both traditional RT and high-speed power training compared to control; however, speed-related changes (PPV and VEL)

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resulting from training continued to favor HSPT compared to STR and CON. Similar to the changes in muscle performance relative to the final 1RM, the change in PP relative to the baseline 1RM was significantly increased with HSPT and STR compared to CON across the spectrum of the power curve but was not significantly different from each other at any point. Although there was no difference in the change in PPT among all 3 groups, PPV and VEL were significantly increased in HSPT compared to STR and CON.

The improvements in PPV and VEL may more accurately reflect training-induced changes in speed characteristics of the muscle compared to examination of changes relative to the final 1RM that reflect movement against a higher absolute mass. Again, these findings are supportive of differential effects of RT on muscle speed characteristics. Surprisingly, we also noted a strong trend in PPV ($p = 0.06$) and significant increases in VEL for our STR group compared to CON. Delmonico et al. (8) compared changes in muscle performance after 10 weeks of traditional slow-speed RT (80–85% 1RM) in older men and women by similarly examining changes relative to the baseline 1RM. Although they found that PPV decreased with slow-speed RT (−7%), we found a near significant increase in PPV across a range of external resistances (range: −1 to 27%) and significant increases in VEL. Delmonico et al. only evaluated PPV at 70% 1RM, whereas this study evaluated PPV and VEL across a range of external resistances. However, even at 70% 1RM, the change in PPV with training in the STR group was still positive (17%) in this study compared to Delmonico et al. Thus, it appears from our data that even slow-velocity RT can increase speed when moving a resistance relative to the baseline 1RM.

Practical Applications

High-speed power training improved speed-related muscle performance characteristics (PPV and VEL) compared to traditional slow-speed RT, particularly at lower external resistances. Based on these findings, we recommend including an RT protocol in older adults that emphasizes high-speed movements at low external resistances (~40% of the 1RM). To increase the velocity component of an activity that is of a low percentage of the 1RM, this study clearly indicates that high-speed power training accomplishes this to an even greater degree than traditional RT. This is important because people often function at percentages of the 1RM well below their maximum, particularly during events that require much greater velocity than force, such as moving the lower limb from the gas pedal to the brake while driving or moving the limb quickly to prevent falling. The application of these findings to RT programs in older adults could have widespread public health implications by possibly increasing the safety of speed-related daily activities in this population. Because most people do not use only 1 style of RT program throughout the lifetime of a fitness regimen, future studies should explore the muscle performance responses to a more practical mixed-method approach including both high-speed and traditional RT.

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