Effect of Power-Training Intensity on the Contribution of Force and Velocity to Peak Power in Older Adults

Nathan J. de Vos, Nalin A. Singh, Dale A. Ross, Theodora M. Stavrinos, Rhonda Orr, and Maria A. Fiatarone Singh

Objective: To determine the effect of training intensity on the contributions of force and velocity to improvements in peak power (PP) after explosive resistance training in older adults. Methods: 112 healthy older adults (69 ± 6 yr) were randomized to explosive resistance training at 20% (G20), 50% (G50), or 80% (G80) maximal strength (1-repetition maximum) for 8–12 wk (twice weekly, 5 exercises, 3 sets of 8 explosive concentric/slow eccentric repetitions) using pneumatic resistance machines or a nontraining control group (CON). Results: Force at peak power (FPP) increased significantly and similarly among training groups compared with CON. Velocity at peak power (VPP) did not improve significantly and remained similar between all groups. Force contributed significantly more to PP production in G80 and G50 than in CON. The change in PP was independently predicted by changes in fat-free mass in G80 and by changes in both FPP and VPP in G50 and G20. Conclusion: Explosive resistance training in older adults results in the ability to produce higher PP outputs with heavier loads without loss of movement velocity. Moderate- to high-intensity training induced a greater relative contribution of force to PP production in this cohort.

Keywords: resistance training, strength, exercise, randomized

Given the faster declines in muscle power than in strength with age (Bosco & Komi, 1980; Izquierdo, Aguado, Gonzalez, Lopez, & Hakkinen, 1999; Labarque, T Eijnde, & Van Leemputte, 2002; Macaluso & De Vito, 2003; Metter, Conwit, Tobin, & Fozard, 1997; Skelton, Greig, Davies, & Young, 1994) and its stronger associations with functional performance and disability (Bassey et al., 1992; Bean et al., 2002; Bean et al., 2003; Cuoco et al., 2004; Foldvari et al., 2000; Hruda, Hicks, & McCartney, 2003; Suzuki, Bean, & Fielding, 2001), recent attention has been directed toward specific resistance-training strategies to improve muscle power in older adults (Bean et al., 2002; de Vos et al., 2005; Earles, Judge, & Gunnarsson, 2001; Fielding et al., 2002; Henwood & Taaffe, 2005; Hruda et al.;

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Macaluso, Young, Gibb, Rowe, & De Vito, 2003; Miszko et al., 2003). Muscle power during a single explosive concentric contraction is determined by the product of force and velocity of movement. Peak power (PP) is defined here and by others (Bean et al., 2002; Earles et al.; Fielding et al.; Foldvari et al.; Thomas, Fiatarone, & Fielding, 1996) as the highest average power output produced (throughout 90% of the movement distance) at any relative intensity (% one-repetition maximum [%1RM]) tested along the force–power curve. Traditional high-intensity, slow-velocity resistance training improves strength (Delmonico et al., 2005; Ferri et al., 2003; Fiatarone et al., 1990; Fiatarone et al., 1994; Jozi, Campbell, Joseph, Davey, & Evans, 1999; Taaffe, Duret, Wheeler, & Marcus, 1999) and might improve PP via increases in the force component of the equation (Delmonico et al.; Ferri et al.). The improvements in PP are typically less, however, than those in strength (Delmonico et al.; Fiatarone et al., 1990; Jozi et al.; Taaffe et al.), perhaps because of a slowing of muscle-contraction velocity at PP (Delmonico et al.). Explosive resistance or power training, whereby the external load is lifted as rapidly as possible, also improves strength (de Vos et al.; Earles et al.; Fielding et al.; Henwood & Taaffe; Hruda et al.; Miszko et al.). The neural stimulus involved with rapid force development might differ from traditional strength training, however, thus improving the velocity at peak power (VPP)—in addition to the force at peak power (FPP)—making it more effective for improving muscle power than traditional resistance training (Fielding et al.). Several studies have reported improvements in peak power after explosive resistance training in older adults (Bean et al., 2002; de Vos et al.; Earles et al.; Fielding et al.; Henwood & Taaffe; Hruda et al.; Macaluso et al., 2003; Miszko et al.); however, the changes in FPP and VPP have rarely been analyzed (Macaluso et al., 2003).

The training intensity used during power training might affect the mechanisms of PP adaptation. Only one study has examined the changes in FPP and VPP after power training and the potential differential effect of training intensity in older adults. Macaluso and colleagues (2003) conducted 16 weeks of power training using sprint cycling on mechanically braked ergometers at high (80% of two-revolution maximum [2RVM]), low (40% 2RVM), or combined (40% and 80% 2RVM) resistances, with equivalent training volumes in 38 healthy older women (age 69 ± 2.7 years). Training induced similar significant improvements in isometric strength and PP (leg press) in the high-, low-, and combined-intensity groups. Furthermore, increases in FPP and VPP were nonsignificant and similar between groups after 16 weeks. The changes in relative contributions of force and velocity to PP between groups were not examined, however.

Despite observing a significant dose-response relationship between explosive resistance-training intensity and increases in strength (1RM), we have previously reported that PP can be improved to a similar extent using low, moderate, or high training intensities (de Vos et al., 2005). Using data from the same cohort of community-dwelling older adults, the current study examined whether the intensity of explosive resistance training alters the contribution of force and velocity to improvements in PP. We hypothesized that improvements in PP would be predominately driven by improvements in velocity in the low-intensity group (20% 1RM) and by improvements in force in the high-intensity group (80% 1RM).
Method

**Study Design**

This was a controlled trial in which participants were randomly allocated to a low-, medium-, or high-intensity training group or a nontraining control group. The duration of the study was originally 8 weeks and later extended to 12 weeks because of additional resource availability.

**Study Population**

Participants were recruited through advertisements, flyers, and presentations and were telephone and physician screened. Inclusion criteria included age ≥60 years, being independent and community dwelling, and being willing to be randomized and commit to the study requirements. Exclusion criteria included participation in resistance- or power-training exercise within the past 6 months (≥1 times/week), acute or terminal illness, myocardial infarction in the past 6 months, unstable cardiovascular or metabolic disease, neuromuscular or musculoskeletal disorders severely disrupting voluntary movement, upper or lower limb amputation, upper or lower extremity fracture in the past 3 months, currently symptomatic hernias or hemorrhoids, and cognitive impairment.

Each participant gave written informed consent. The Central Sydney Area Health Service Ethics Review Committee and The University of Sydney Human Ethics Committee approved this study.

**Testing Procedures**

**Participant Characteristics.** Testing of all outcome measures was conducted before randomization and after 8 or 12 weeks of enrollment. Fasting body weight, height, and bioelectrical-impedance estimates of fat and fat-free mass (FFM) were determined using standard procedures (BIA-101; RJL Systems, Detroit, MI; Lukaski, Bolunchuk, Hall, & Siders, 1986; Roubenoff et al., 1997).

**Muscle-Power and -Velocity Testing.** Muscle power was assessed on digital Keiser pneumatic resistance machines fitted with A400 electronics (Keiser Sports Health Equipment, Fresno, CA) in five exercises: bilateral horizontal leg press, seated chest press, bilateral knee extension, seated row, and seated bilateral knee flexion. After 30 min of rest following measurement of the 1RM (described elsewhere [de Vos et al., 2005]), muscle power (W) was assessed at 10 relative intensities (20%, 40%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, and 85% 1RM). Participants were instructed to complete the concentric portion of the repetition as rapidly as possible, then to slowly lower the weight over 3 s. All trials were verbally cued “1, 2, 3, go!” One trial was given at each of the 10 loads specified, separated by 30- to 60-s rest periods. Keiser A400 software calculated work and power during the concentric phase of the repetition by sampling the system pressure (force) and position (via ultrasonic position transducers) at a rate of 400 times per second. Accuracy of system pressure and position are reported by the manufacturer to be within 1%. Power and velocity were calculated as the average respective value between 5% and 95% of the concentric phase of the repetition to eliminate noisy
data at the beginning and end points of motion. The highest average power produced throughout the loads tested was recorded as the PP. The resistance used and the average velocity produced during this repetition were designated the FPP and VPP, respectively. The loads used to assess final power after the intervention were relative to the final 1RM, not the baseline 1RM.

**Training Intervention**

Details of the training intervention have been described elsewhere (de Vos et al., 2005). Briefly, participants randomized to the three experimental groups performed explosive resistance training at one of three intensities using training loads equivalent to 20% (G20), 50% (G50), or 80% (G80) of their 1RM. Participants trained 2 days per week for 8 or 12 weeks using analog Keiser pneumatic resistance-training machines (Keiser Sports Health Equipment). The same five exercises used for testing were performed for two sets of eight rapid concentric and slow eccentric repetitions. Participants in the control group (CON) did not undergo any training and were instructed to maintain their usual level of physical activity.

**Data Analysis**

After initially analyzing each exercise separately and finding similar changes, composite data of the 5 exercises were calculated for analysis of “whole body” outcomes (Singh, Clements, & Fiatarone, 1999; Taaffe et al., 1999) to minimize the complexity and length of the manuscript and present an overall effect of power training at each intensity. The following variables were calculated: average relative intensity at PP (sum of %1RM at PP in each exercise/5), total FPP (sum of FPP in each exercise), and total VPP (sum of VPP in each exercise). FPP:VPP ratio was calculated for each individual in each exercise, with the mean among all exercises reported as the average FPP:VPP ratio. Average percentage change values for FPP and VPP were also calculated. The percentage change ([final – baseline]/baseline value × 100) for each individual was calculated in each exercise, with the mean change among all exercises analyzed between groups.

**Statistical Analysis**

All statistical procedures were performed using the StatView statistical software package (Abacus Concepts, Berkeley, CA). Computer-generated randomization plans (Dallal) were designed, blocked in groups of four, and stratified by sex. Normal distribution of baseline data was assessed using histograms and descriptive statistics. Values are presented as $M \pm SD$. Equivalence between groups at baseline was assessed for all descriptive and performance variables by using analysis of variance (ANOVA) for continuous, and chi-square tests for categorical, variables. Repeated-measures ANOVA and analysis of covariance (ANCOVA) adjusted for baseline values were used to analyze the effects of training intensity on outcome variables over time and to identify any group-by-time interactions. Fisher-protected least-significant-difference post hoc $t$ tests were used to identify sources of differences. Linear regression was used to reveal pertinent relationships between variables at baseline and between changes in outcome variables.
and PP after the intervention. Forward stepwise regression was then used to determine independent contributions of outcome variables on the change in PP. When more than one variable was found to be independently related to the change in PP, the standardized coefficient was used to determine the relative contribution of each variable. In the StatView statistical software used, standardized coefficients are calculated as if all the independent variables had a variance of 1; thus, two standardized coefficients can be directly compared, regardless of differences in the scale of the variables involved. Statistical significance was accepted at \( p < .05 \).

## Results

### Attrition, Compliance, and Adverse Events

Twelve participants (11%) dropped out of the study, 4 from G80, 3 from G50, 3 from G20, and 2 from CON. Specific reasons for dropout in each group have been published elsewhere (de Vos et al., 2005). Participants who dropped out did not return for final testing and are not included in the final statistical analysis.

Compliance was calculated as the number of training sessions attended divided by the number of sessions held. Compliance for all participants, including the 12 dropouts, was 90% ± 19% for G80, 88% ± 25% for G50, 92% ± 10% for G20, and 98% ± 10% for CON, with no difference between groups (\( p = .12 \)).

Some participants experienced minor musculoskeletal discomfort during the training intervention. Details of adverse events in this group have been published elsewhere (de Vos et al., 2005). Four participants from G80, 5 from G50, and 1 from G20 did not complete final testing on one or more machines after consultation with the study physician. Only participants completing all five exercises are included in the final statistical analysis.

### Baseline Characteristics

Participant characteristics are presented in Table 1. Baseline performance measures are presented in Table 2. There was no significant difference between groups for any characteristic or performance variable at baseline.

### Percent 1RM at Peak Power

Average %1RM at PP decreased significantly over time (\( p = .001 \)) with no significant Group × Time interaction (\( p = .502 \)). Changes in average %1RM at PP were –2.6% ± 4.5%1RM, –2.5% ± 4.4%1RM, –1.0% ± 4.7%1RM, –1.2% ± 3.5%1RM in G80, G50, G20, and CON, respectively (Figure 1).

### FPP

Total FPP increased over time (\( p < .001 \)), with a significant Group × Time interaction observed (\( p = .007 \)). Average percentage changes in FPP were 16% ± 10%, 13% ± 11%, 12% ± 11%, and 2% ± 6% in G80, G50, G20, and CON, respectively, with similarly greater improvement in the training groups (\( p = .629–.183 \)) than in
Table 1  Participant Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (N = 112)</th>
<th>G80 (n = 28)</th>
<th>G50 (n = 28)</th>
<th>G20 (n = 28)</th>
<th>CON (n = 28)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>68.5 (5.7)</td>
<td>69.0 (6.4)</td>
<td>68.1 (4.5)</td>
<td>69.4 (5.8)</td>
<td>67.6 (6.0)</td>
<td>.63</td>
</tr>
<tr>
<td>% Men</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>71.4 ± 12.4</td>
<td>71.1 ± 13.1</td>
<td>72.4 ± 12.6</td>
<td>71.9 ± 14.2</td>
<td>70.4 ± 13.3</td>
<td>.95</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.5 ± 9.2</td>
<td>165.1 ± 11.0</td>
<td>165.1 ± 6.9</td>
<td>165.3 ± 10.6</td>
<td>166.7 ± 7.9</td>
<td>.90</td>
</tr>
<tr>
<td>Body-mass index (kg/m²)</td>
<td>26 ± 3.6</td>
<td>26 ± 3.3</td>
<td>26.5 ± 3.9</td>
<td>26.2 ± 3.7</td>
<td>25.2 ± 3.8</td>
<td>.62</td>
</tr>
<tr>
<td>Fat-free mass (kg)a</td>
<td>46.3 ± 9.8</td>
<td>46.7 ± 10.3</td>
<td>46.7 ± 9.0</td>
<td>45.8 ± 10.3</td>
<td>46.2 ± 9.9</td>
<td>.98</td>
</tr>
<tr>
<td>Body fat (kg)</td>
<td>25.1 ± 7.5</td>
<td>24.4 ± 6.4</td>
<td>25.7 ± 8.2</td>
<td>26.1 ± 8.6</td>
<td>24.2 ± 6.9</td>
<td>.72</td>
</tr>
<tr>
<td>Regular medications (no./day)</td>
<td>1 (0–7)</td>
<td>1 (0–7)</td>
<td>1 (0–7)</td>
<td>1 (0–6)</td>
<td>1 (0–6)</td>
<td>.95</td>
</tr>
<tr>
<td>Medical diagnoses (no.)</td>
<td>1 (0–4)</td>
<td>1 (0–4)</td>
<td>1 (0–3)</td>
<td>0.5 (0–3)</td>
<td>1 (0–4)</td>
<td>.77</td>
</tr>
<tr>
<td>Fallers (%)b</td>
<td>21</td>
<td>11</td>
<td>32</td>
<td>21</td>
<td>21</td>
<td>.28</td>
</tr>
</tbody>
</table>

Note. G80 = high-intensity (80% 1RM) group; G50 = medium-intensity (50% 1RM) group; G20 = low-intensity (20% 1RM) group; CON = control group. Values of normally distributed data are presented as M ±SD. Skewed data are presented as medians and ranges. The p values were determined by chi-square for fallers, Kruskal–Wallis ANOVA for regular medications and medical diagnosis, and factorial ANOVA for others. A p value of <.05 was accepted as statistically significant. aFat-free mass was determined using bioelectrical-impedance analysis (Lukaski et al., 1986). bFallers refers to the percentage of participants who had 1 or more falls in the past 12 months.
Table 2  Baseline Performance Measures

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (N = 112)</th>
<th>G80 (n = 28)</th>
<th>G50 (n = 28)</th>
<th>G20 (n = 28)</th>
<th>CON (n = 28)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>%1RM at peak power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>leg press</td>
<td>62 ± 8</td>
<td>61 ± 7</td>
<td>60 ± 6</td>
<td>61 ± 9</td>
<td>64 ± 7</td>
<td>.13</td>
</tr>
<tr>
<td>chest press</td>
<td>56 ± 6</td>
<td>57 ± 6</td>
<td>55 ± 7</td>
<td>55 ± 5</td>
<td>57 ± 5</td>
<td>.62</td>
</tr>
<tr>
<td>knee extension</td>
<td>75 ± 9</td>
<td>75 ± 9</td>
<td>74 ± 9</td>
<td>74 ± 10</td>
<td>78 ± 7</td>
<td>.28</td>
</tr>
<tr>
<td>seated row</td>
<td>78 ± 7</td>
<td>80 ± 5</td>
<td>79 ± 8</td>
<td>77 ± 7</td>
<td>75 ± 10</td>
<td>.06</td>
</tr>
<tr>
<td>knee flexion</td>
<td>61 ± 8</td>
<td>60 ± 10</td>
<td>59 ± 8</td>
<td>62 ± 5</td>
<td>63 ± 8</td>
<td>.49</td>
</tr>
<tr>
<td>average %1RM at peak powerb</td>
<td>66 ± 4</td>
<td>67 ± 4</td>
<td>65 ± 4</td>
<td>66 ± 5</td>
<td>67 ± 3</td>
<td>.24</td>
</tr>
<tr>
<td>Force at peak power (FPP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>leg press, N</td>
<td>677 ± 232</td>
<td>714 ± 237</td>
<td>652 ± 220</td>
<td>613 ± 206</td>
<td>685 ± 244</td>
<td>.35</td>
</tr>
<tr>
<td>chest press, N</td>
<td>156 ± 67</td>
<td>169 ± 52</td>
<td>170 ± 59</td>
<td>136 ± 52</td>
<td>152 ± 57</td>
<td>.12</td>
</tr>
<tr>
<td>knee extension, Nm</td>
<td>101 ± 38</td>
<td>109 ± 43</td>
<td>100 ± 35</td>
<td>89 ± 31</td>
<td>104 ± 38</td>
<td>.32</td>
</tr>
<tr>
<td>seated row, N</td>
<td>179 ± 77</td>
<td>185 ± 68</td>
<td>185 ± 61</td>
<td>165 ± 67</td>
<td>174 ± 59</td>
<td>.17</td>
</tr>
<tr>
<td>knee flexion, Nm</td>
<td>84 ± 27</td>
<td>85 ± 28</td>
<td>81 ± 21</td>
<td>78 ± 25</td>
<td>86 ± 27</td>
<td>.60</td>
</tr>
<tr>
<td>total FPPc</td>
<td>1,200 ± 298</td>
<td>1,238 ± 392</td>
<td>1,170 ± 356</td>
<td>1,077 ± 363</td>
<td>1,195 ± 416</td>
<td>.57</td>
</tr>
<tr>
<td>Velocity at peak power (VPP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>leg press, cm/s</td>
<td>75 ± 11</td>
<td>71 ± 12</td>
<td>78 ± 7</td>
<td>73 ± 9</td>
<td>74 ± 12</td>
<td>.27</td>
</tr>
<tr>
<td>chest press, cm/s</td>
<td>98 ± 18</td>
<td>95 ± 19</td>
<td>101 ± 17</td>
<td>94 ± 19</td>
<td>97 ± 16</td>
<td>.69</td>
</tr>
<tr>
<td>knee extension, rad/s</td>
<td>2.47 ± 0.42</td>
<td>2.36 ± 0.35</td>
<td>2.61 ± 0.45</td>
<td>2.41 ± 0.42</td>
<td>2.44 ± 0.40</td>
<td>.42</td>
</tr>
<tr>
<td>seated row, cm/s</td>
<td>159 ± 25</td>
<td>163 ± 23</td>
<td>156 ± 28</td>
<td>154 ± 25</td>
<td>160 ± 26</td>
<td>.66</td>
</tr>
<tr>
<td>knee flexion, rad/s</td>
<td>3.02 ± 0.45</td>
<td>2.98 ± 0.47</td>
<td>3.09 ± 0.39</td>
<td>2.93 ± 0.46</td>
<td>3.01 ± 0.50</td>
<td>.47</td>
</tr>
<tr>
<td>total VPPc</td>
<td>338 ± 46</td>
<td>329 ± 44</td>
<td>335 ± 44</td>
<td>325 ± 45</td>
<td>338 ± 45</td>
<td>.74</td>
</tr>
<tr>
<td>Average FPP:VPPb</td>
<td>16.4 ± 5.1</td>
<td>17.4 ± 5.5</td>
<td>15.6 ± 3.6</td>
<td>15.4 ± 5.8</td>
<td>17.1 ± 5.4</td>
<td>.38</td>
</tr>
</tbody>
</table>

Note. G80 = high-intensity (80% 1RM) group; G50 = medium-intensity (50% 1RM) group; G20 = low-intensity (20% 1RM) group; CON = control group. Values are presented as M ± SD. A p value of <.05 was accepted as statistically significant. Factorial ANOVA was used to analyze differences between groups at baseline.

N = 110 for chest-press exercise—1 participant from G80 and G20 was excluded from performing this exercise. Average %1RM at peak power and average FPP: VPP (n = 110) = summed value of the 5 exercises divided by 5. Total force and velocity at peak power (n = 110) = summed value of the 5 exercises.
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Average percentage change in FPP was significantly related to percentage change in FFM in G80 ($r = .465$, $p = .039$).  

There was no significant change in total VPP ($p = .373$) or difference between groups after the intervention ($p = .178$). Average percentage changes in VPP were $1.4\% \pm 8.5\%$, $4.9\% \pm 7.2\%$, $5.3\% \pm 9.1\%$, and $2.3\% \pm 6.9\%$ in G80, G50, G20, and CON, respectively, with no significant group differences ($p = .405$; Figure 1). Among training groups, lower initial VPP was associated with greater average percentage change in VPP ($r = -.493$, $p < .001$) and PP ($r = -.265$, $p = .034$). Average percentage change in VPP was not significantly associated with change in FFM in any group ($p = .871-.618$).  

The FPP:VPP ratio indicates the relative contribution of FPP and VPP to PP. Changes in this ratio after training would suggest a shift in the mechanics of PP generation. Average FPP:VPP ratio increased over time ($p = .007$), with a significant Group $\times$ Time interaction observed ($p = .015$). Increases were greater in G80 ($p = .001$) and G50 ($p = .027$) than in CON and tended to be greater in G20 than in CON ($p = .06$; Figure 2). Post hoc power analyses using a power ($\beta$) of .8 and $\alpha = .05$ revealed that a sample size of 136 participants (68 per group) would be needed to detect a significant difference between the change in average FPP:VPP between G80 and G20.

Figure 1 — Average change in %1RM at peak power (gray bars), and average percentage change in force at peak power (black bars), and velocity at peak power (white bars), after explosive resistance training in older adults. Values are $M \pm SD$ averaged across the five exercises. G80 = high-intensity (80% 1RM) group; G50 = medium-intensity (50% 1RM) group; G20 = low-intensity (20% 1RM) group; CON = control group. ANCOVA models were adjusted for baseline values. revealed *Significantly greater than CON ($p < .001$) according to Fisher-protected least-significant-difference post hoc comparisons.
Body Composition

There was no significant change in body weight, height, body-mass index, body fat, or FFM (p = .905–.221) or difference between groups after the intervention (p = .318–.074) as previously reported (de Vos et al., 2005). Specifically, values for nonsignificant changes in FFM were 0.30 ± 1.1 kg in G80, –0.29 ± 1.3 kg in G50, 0.69 ± 1.7 kg in G20, and –0.15 ± 1.7 kg in CON.

Predictors of Percentage Change in Peak Power

Simple and forward stepwise regressions were performed in each training group separately to determine potential mechanisms of power improvements with training. Univariate associations between percentage changes in FFM, FPP, and VPP and improvements in PP are presented in Table 3. Improvements in PP were associated with increased FFM in G80 only (r = .574, p = .008) and with increased FPP in all training groups (r = .488–.655, p = .019–.002). Improvements in PP were not associated with changes in VPP in any training group (r = .132–.276, p = .580–.192). When these three variables were entered into a forward stepwise-regression model, increased FFM was the only independent predictor of PP improvement (R^2 = .329, p = .008) in G80. Increases in both FPP and VPP independently predicted improvement in PP in G50 (r = .916, R^2 = .838, p < .001) and G20 (r = .935, R^2 = .874, p < .001), explaining 84% and 87% of the variance, respectively. The increase in FPP, compared with that in VPP, contributed relatively more to the change in PP in both G50 (standardized coefficient: FPp =
1.019, \( VP_p = 0.736 \)) and G20 (standardized coefficient: \( FP_p = 1.190, VP_p = 1.062 \)).

**Discussion**

This is the first study to examine the influence of training intensity on the determinants of PP using this mode of power training (pneumatic resistance machines) in independent older men and women. Contrary to our hypothesis, we found that training using loads of 20%, 50%, or 80% of 1RM produced similar increases in FPP without changing VPP. The contribution of force to PP increased with moderate-to high-intensity training, however, yet tended to remain the same with low-intensity training, suggesting that improvements in PP depend less on improvements in force with low-intensity training. Similarly, only in the high-intensity group did change in FFM predict changes in muscle power. Thus, anabolic adaptations in FFM and strength contribute to power predominantly or exclusively after moderate-to high-intensity training paradigms.

Our finding of similar increases in FPP with high and low intensities of power training is consistent with the observations of Macaluso and colleagues (2003). We have previously demonstrated a dose-response relationship between training intensity and muscle strength and endurance in this cohort (de Vos et al., 2005), however. The relative intensity at which PP was generated decreased in all groups, producing a leftward shift of PP along the force–power curve in agreement with results of previous research (Izquierdo et al., 2001). Had all groups produced PP at the same relative intensity after training, the differences in FPP between groups would be expected to match those of strength. Thus, the nonsignificantly greater shifts from the highest (2.6%) to the lowest (1%) intensity training groups (Figure 1) are likely responsible for attenuating the group differences in FPP previously observed for strength improvements.

In previous research, increases in PP have occurred despite decreases in VPP after strength (Delmonico et al., 2005) and power training (Earles et al., 2001).

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**Table 3** Univariate Associations With Average Percentage Change in Peak Power

<table>
<thead>
<tr>
<th>Group</th>
<th>Variable</th>
<th>( r )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>G80 (n = 20)</td>
<td>Fat-free mass (% change)</td>
<td>.574</td>
<td>.008</td>
</tr>
<tr>
<td></td>
<td>Force at peak power (average % change)</td>
<td>.520</td>
<td>.019</td>
</tr>
<tr>
<td></td>
<td>Velocity at peak power (average % change)</td>
<td>.132</td>
<td>.580</td>
</tr>
<tr>
<td>G50 (n = 20)</td>
<td>Fat-free mass (% change)</td>
<td>.328</td>
<td>.153</td>
</tr>
<tr>
<td></td>
<td>Force at peak power (average % change)</td>
<td>.655</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td>Velocity at peak power (average % change)</td>
<td>.232</td>
<td>.325</td>
</tr>
<tr>
<td>G20 (n = 24)</td>
<td>Fat-free mass (% change)</td>
<td>.218</td>
<td>.306</td>
</tr>
<tr>
<td></td>
<td>Force at peak power (average % change)</td>
<td>.488</td>
<td>.016</td>
</tr>
<tr>
<td></td>
<td>Velocity at peak power (average % change)</td>
<td>.276</td>
<td>.192</td>
</tr>
</tbody>
</table>

*Note.* G80 = high-intensity (80% 1RM) group; G50 = medium-intensity (50% 1RM) group; G20 = low-intensity (20% 1RM) group. Bold type indicates \( p < .05 \).
Recently, Delmonico and colleagues conducted a 10-week high-intensity (80–85% 1RM) strength-training program in older men and women. Although training significantly increased strength and PP (produced at the same %1RM as before training), the VPP decreased by 7%. Earles and colleagues conducted 12 weeks of power training in older adults, reporting significant improvements in strength and PP (22%). Although the authors did not present changes in VPP, based on their force–power and velocity plots it can be seen that PP was generated at 30% body weight before training and 50% body weight after training, with an obvious decrease in VPP at this heavier load (~45%). This decrease can be largely attributed to PP’s being generated at a much higher relative intensity after training rather than a slowing of muscle velocity per se. In contrast with the cited studies, and in agreement with Macaluso and colleagues (2003), the current study found no change in VPP after power training. Therefore, power training, as it has been conducted in studies to date, does not seem to improve the age-related decline in VPP (Macaluso & De Vito, 2003). The force–velocity relationship dictates that contraction velocity increases as relative intensity decreases (Wickiewicz, Roy, Powell, Perrine, & Edgerton, 1984). Thus, the lack of group difference might be partly attributed to the slightly greater decrease in the relative intensity at which PP was produced in the high-intensity group. The fact that the change in VPP was somewhat higher in the low-intensity group (Figure 1) despite little change in the relative intensity at which PP was produced makes the improvement of velocity with low-load training relatively greater. Nevertheless, in all training groups, improvements in PP were primarily the result of participants’ being able to move greater loads without losing movement velocity.

This study found that moderate- to high-intensity explosive resistance training altered the contribution of force and velocity to PP, as indicated by significant increases in FPP:VPP ratio compared with CON. Intensity-dependent trends have been reported in young men (Kaneko, Fuchimoto, Toji, & Suei, 1983), with speed:strength ratio tending to increase after elbow-flexor power training using light loads and decrease after training using moderate or maximal loads, suggestive of a greater relative contribution of velocity to power after low-intensity training. Sample sizes 3 times larger than our current cohort would be needed, however, to present significant differences between low- and high-intensity groups.

Low-load (40% 1RM) contraction velocity has been shown to be a predictor of functional performance in older adults (Sayers, Guralnik, Thoms, & Fielding, 2005) and, recently, of balance improvement after low-intensity power training in this cohort (Orr et al., 2006). In the current study, individuals with lower initial VPP had the greatest relative improvements in PP. In frail institutionalized older adults, power-training-induced improvements in leg-muscle power are related to improvements in agility and maximal gait speed (Hruda et al., 2003). Thus, the velocity, rather than the force, component of PP might be a more sensitive indicator of the potential for improving power and perhaps balance or functional impairment (Orr et al.). Future studies should examine the relationship between improvements in velocity and power and physical function and falls risk after power training in frail or mobility-impaired elders.

In the current study, increases in FFM were associated with improvements in FPP and independently predicted improvements in PP in the high-intensity group. Thus, improvements in PP are more dependent on increases in muscle mass after
high-intensity training than after moderate- or low-intensity training. The absence of significant increases in FFM, however, suggests that the mechanisms of adaptation were primarily neural after the relatively short 10-week intervention we employed, as would be expected. Although we did not assess neural activity, possible mechanisms of increased PP via increased FPP might include increased activation (Hakkinen, Alen, Kallinen, Newton, & Kraemer, 2000; Hakkinen et al., 2001; Macaluso et al., 2003) and coordination of agonist and decreased cocontraction of antagonist muscles (Hakkinen et al., 2000; Hakkinen et al., 1998). Increases in tendon stiffness after resistance training might also contribute to enhanced transmission of force and consequent power production (Reeves, Maganaris, & Narici, 2003), although such adaptations remain to be demonstrated after power training.

There were limitations to this study. Weekly strength testing ensured that training intensity was accurately maintained (de Vos et al., 2005). It might have provided a once-weekly, high-intensity training stimulus to the lighter training groups, however, and influenced their improvements in FPP (strength) and PP. The duration of the study was relatively short. A longer intervention or greater volume of exercise might reveal differences among groups for PP and body composition. A more sensitive measure of body composition, such as dual X-ray absorptiometry, would have been preferable; however, we did not have the resources for this method of assessment. Nonblinded final testing could have biased the results. Finally, generalizations are limited to independent, relatively highly functioning (Orr et al., 2006) older adults.

In summary, our findings demonstrate that improvements in PP after explosive resistance training occur primarily as a result of improved force production. The velocity at which PP is produced does not change, with the contribution of force and FFM to PP production increasing with moderate- to high-intensity training. Practically, this equates to the ability to lift heavier loads at the same optimal speed for PP production. There might be a trend for force to contribute less (and velocity more) to the improvements in PP with low-intensity than with high-intensity training, which will require larger sample sizes to confirm. Future studies should also examine the effect of training intensity on power, force, and velocity adaptations at relative loads other than that at which PP is produced (i.e., low loads), which might have greater relevance to various tasks of functional performance (Cuoco et al., 2004).

Our studies have shown that high-intensity training best improves muscle strength and endurance (de Vos et al., 2005), low-intensity training best improves balance performance (Orr et al., 2006), and relative improvements in PP might be achieved equally with low-, moderate-, or high-intensity training (de Vos et al.). Therefore, the optimal power-training prescription remains to be defined and should be tailored to best correct the underlying deficits in exercise capacity most relevant to a given individual.

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