The Effect of Explosive Resistance Training Intensity on the Contribution of Force and Velocity to Peak Power Generation in Older Adults: A Randomized Controlled Trial

Nathan J. de Vos, PhD (Ex&SportSci)[1], Nalin A. Singh, MBBS[2,3], Dale A. Ross, BHMS[2], Theodora M. Stavrinos, MPH[2], Rhonda Orr, MApplSc (Ex&SportSci)[1], and Maria A. Fiatarone Singh, MD[1,4,5]

[1] Discipline of Exercise, Health and Performance, Faculty of Health Sciences, The University of Sydney, Sydney, NSW, Australia.

[2] Balmain Hospital, Sydney, NSW, Australia.

[3] Royal Prince Alfred Hospital, Sydney, NSW, Australia.

[4] Hebrew SeniorLife, Boston, MA.

[5] Jean Mayer USDA Human Nutrition Research Center on Aging, Tufts University, Boston, MA.

Corresponding Author: Nathan J. de Vos, PhD (Ex&SportSci)

Mailing Address:
Discipline of Exercise, Health and Performance
The University of Sydney
75 East Street
Lidcombe, NSW, 2141
Australia

E-mail: devos@optusnet.com.au

Phone/Fax: 61-2-9606-6193

This paper was presented at the 59th Annual Scientific Meeting of the Gerontological Society of America, Dallas, Texas, on November 19, 2006, and was subsequently published as an abstract in *The Gerontologist 46:* 408

Funding source: Discipline of Exercise, Health and Performance, Faculty of Health Sciences, The University of Sydney, NSW, Australia.

Running Head: Force and Velocity Following Power Training in Elderly

Abstract

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 yrs) were randomized to explosive resistance training at 20% (G20), 50% (G50), or 80% (G80) maximal strength (1RM) for 8-12 weeks (twice weekly; five exercises; 3 sets of 8 explosive concentric/slow eccentric repetitions) using pneumatic resistance machines or a non-training control group.

Results: Force at peak power (FPP) increased significantly and similarly among training groups compared to controls. 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 compared to controls. 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 peak power 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.

Given the faster declines in muscle power compared to strength with age (Bosco & Komi, 1980; Izquierdo, Aguado, Gonzalez, Lopez, & Hakkinen, 1999; Labarque, T Eunde, & 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, J. F. 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 towards specific resistance training strategies to improve muscle power in older adults (Bean, J. et al., 2002; de Vos et al., 2005; Earles, Judge, & Gunnarsson, 2001; Fielding et al., 2002; Henwood & Taaffe, 2005; Hruda et al., 2003; 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 is defined here and by others (Bean, J. et al., 2002; Earles et al., 2001; Fielding et al., 2002; Foldvari et al., 2000; 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 may improve peak power via increases in the force component of the equation (Delmonico et al., 2005; Ferri et al., 2003). However, the improvements in peak power are typically less than those of strength (Delmonico et al., 2005; Fiatarone et al., 1990; Jozi et al., 1999; Taaffe et al., 1999) perhaps due to a slowing of muscle contraction velocity at peak power (Delmonico et al., 2005). Explosive resistance or power training, whereby the external load is lifted as rapidly as possible, also improves strength (de Vos et al., 2005; Earles et al., 2001; Fielding et al., 2002; Henwood & Taaffe, 2005; Hruda et al., 2003; Miszko et al., 2003). However, the neural stimulus involved with rapid force development may differ to traditional strength training, 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., 2002). Several studies have reported improvements in peak power following explosive resistance training in older adults (Bean, J. et al., 2002; de Vos et al., 2005; Earles et al., 2001; Fielding et al., 2002; Henwood & Taaffe, 2005; Hruda et al., 2003; Macaluso et al., 2003; Miszko et al., 2003), however, the changes in force and velocity at peak power are rarely analyzed (Macaluso et al., 2003).

The training intensity used during power training may potentially affect the mechanisms of peak power 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 et al., 2003). Macaluso and colleagues (Macaluso et al., 2003) conducted 16 weeks of power training using sprint-cycling on mechanically braked ergometers at high (80% of 2 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 yrs). 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 non significant and similar between groups after 16 weeks. However, the changes in relative contributions of force and velocity to PP between groups were not examined.

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 present 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).

Methods

Study Design

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

Study Population

Recruitment and Screening.

Participants were recruited through advertisements/flyers/presentations and were telephone and physician screened. Inclusion criteria included age ≥ 60 years, independent/community dwelling, willing to be randomized and commit to the study requirements. Exclusion criteria included participation in resistance/power training exercise within past 6 months (≥ 1 x/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, or cognitive impairment.

Each participant gave their 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 were conducted before randomization and after 8 or 12 weeks of enrolment. Fasting body weight, height, and bioelectrical impedance estimates of fat and fat-free mass were taken 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 minutes 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 seconds. All trials were verbally cued “1, 2, 3, GO!” One trial was given at each of the 10 loads specified, separated by a 30- to 60-second rest period. 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 analogue Keiser pneumatic resistance-training machines (Keiser Sports Health Equipment). The same five exercises used for testing were performed for 2 sets of 8 rapid concentric, 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 analysing 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 minimise the complexity and length of the manuscript and present an overall effect of power training at each intensity. The following variables were calculated as follows: 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 average FPP/VPP ratio. Average percentage change values for FPP and VPP were also created. The percentage change ([final – baseline]/baseline value x 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 means ± standard deviation (*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 source of differences. Linear regression was used to reveal pertinent relationships between variables at baseline, and between changes in outcome variables and PP following 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 of the independent variables had variance 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, four from G80, three from G50, three from G20; and two from CON. Specific reasons for dropouts 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 group have been published elsewhere (de Vos et al., 2005). Four participants from G80, five from G50, and one from G20 did not complete final testing on one or more machines following 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.

%1RM at Peak Power

Average %1RM at PP decreased significantly over time (*P*=.001) with no significant group x 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).

Force at Peak Power (FPP)

Total FPP increased over time (*P*<.001) with a significant group x 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) compared to controls (*P*=.004-<.001) (Figure 1). Average percentage change in FPP was significantly related to percentage change in FFM in G80 (r=.465, *P*=.039).

Velocity at Peak Power (VPP)

There was no significant change in total VPP (*P*=.373) or difference between groups following the intervention (*P*=.178). Average percentage changes in VPP were 1.4±8.5%, 4.9±7.2%, 5.3±9.1%, and 2.3±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).

FPP/VPP Ratio

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 peak power generation. Average FPP/VPP ratio increased over time (*P*=.007) with a significant group x time interaction observed (*P*=.015). Increases were greater in G80 (*P*=.001) and G50 (*P*=.027) compared to CON, and tended to be greater in G20 than CON (*P*=.06) (Figure 2). Post-hoc power analyses using a power (β) of 0.8 and α = .05 revealed 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.

Body Composition

There was no significant change in body weight, height, body mass index, body fat, or FFM (*P*=.905 to .221) or difference between groups following the intervention (*P*=.318 to .074) as previously reported (de Vos et al., 2005). Specifically, values for non-significant 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 to .655, *P*=.019-.002). Improvements in PP were not associated with changes in VPP in any training group (r=.132 to .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 to that of VPP, contributed relatively more to the change in PP in both G50 (standardized coefficient: FPP = 1.019; VPP = 0.736) and G20 (standardized coefficient: FPP = 1.190; VPP = 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 training using loads of 20%, 50%, or 80% of the 1RM produced similar increases in FPP without changing VPP. However, the contribution of force to PP increased with moderate to high intensity training, yet tended to remain the same with low intensity training, suggesting improvements in PP are less dependent 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-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 (Macaluso et al., 2003). However, we have previously demonstrated a dose-response relationship between training intensity and muscle strength and endurance in this cohort (de Vos et al., 2005). The relative intensity at which PP was generated decreased in all groups producing a left-ward shift of PP along the force-power curve in agreement with 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 non-significantly 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 following strength (Delmonico et al., 2005) and power training (Earles et al., 2001). Recently, Delmonico and colleagues (Delmonico et al., 2005) conducted a 10 week high intensity (80-85%1RM) strength training program in older men and women. While training significantly increased strength and PP (produced at the same %1RM as prior to training), the VPP decreased by 7%. Earles and colleagues (Earles et al., 2001) 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% bodyweight before training and 50% bodyweight after training with an obvious decrease in VPP at this heavier load (~45%). This decrease can be largely attributed to PP being generated at a much higher relative intensity after training rather than a slowing of muscle velocity per se. In contrast with the above studies, and in agreement with Macaluso and colleagues (Macaluso et al., 2003), the present 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 may 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 loss of 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 to controls. 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. However, sample sizes three times larger than our current cohort would be needed to present significant differences between low and high intensity groups.

Low load (40%1RM) contraction velocity has shown to be a predictor of functional performance in older adults (Sayers, Guralnik, Thombs, & Fielding, 2005), and recently, of balance improvement following low intensity power training in this cohort (Orr et al., 2006). In the present 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 may be a more sensitive indicator of the potential for improvements in power and perhaps balance or functional impairment (Orr et al., 2006). Future studies should examine the relationship between improvements in velocity and power and physical function and falls risk following power training in frail or mobility impaired elders.

In the present 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 relatively more dependent upon increases in muscle mass following high intensity training than moderate or low intensity training. However, the absence of significant increases in FFM suggests 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 may include increased activation (Hakkinen, Alen, Kallinen, Newton, & Kraemer, 2000; Hakkinen et al., 2001b; Macaluso et al., 2003) and co-ordination of agonist and decreased co-contraction of antagonist muscles (Hakkinen et al., 2000; Hakkinen et al., 1998b). Increases in tendon stiffness following resistance training may 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 training intensity was accurately maintained (de Vos et al., 2005). However, it may have provided a once-weekly, high-intensity training stimulus to the lighter training groups 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 may 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. Non-blinded 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 peak power is produced does not change, with the contribution of force and fat-free mass 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 may be a trend for force to contribute less (and velocity more) to the improvements in PP with low intensity compared to 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 peak power is produced (i.e. low loads) which may have greater relevance to various tasks of functional performance (Cuoco et al., 2004).

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

References

Bassey, E. J., Fiatarone, M. A., O'Neil, E. F., Kelly, M., Evans, W. J., & Lipsitz, L. A. (1992). Leg extensor power and functional performance in very old men and women. *Clinical Science, 82*(3), 321-327.

Bean, J., Herman, S., Kiely, D. K., Callahan, D., Mizer, K., Frontera, W. R., et al. (2002). Weighted stair climbing in mobility-limited older people: A pilot study. *Journal of the American Geriatrics Society, 50*(4), 663-670.

Bean, J. F., Kiely, D. K., Herman, S., Leveille, S. G., Mizer, K., Frontera, W. R., et al. (2002). The relationship between leg power and physical performance in mobility-limited older people. *Journal of the American Geriatrics Society, 50*(3), 461-467.

Bean, J. F., Leveille, S. G., Kiely, D. K., Bandinelli, S., Guralnik, J. M., & Ferrucci, L. (2003). A comparison of leg power and leg strength within the inchianti study: Which influences mobility more? *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 58A*(8), 728-733.

Bosco, C., & Komi, P. V. (1980). Influence of aging on the mechanical behavior of leg extensor muscles. *European Journal of Applied Physiology, 45*(2-3), 209-219.

Cuoco, A., Callahan, D., Sayers, S., Frontera, W. R., Bean, J., & Fielding, R. A. (2004). Impact of muscle power and force on gait speed in disabled older men and women. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 50A*(11), 1200-1206.

Dallal, G. E. (7/28/2003). *Randomization.Com*. Retrieved July 28, 2002, 2002, from http://www.randomization.com

Delmonico, M. J., Kostek, M. C., Doldo, N. A., Hand, B. D., Bailey, J. A., Rabon-Stith, K. M., et al. (2005). Effects of moderate-velocity strength training on peak muscle power and movement velocity: Do women respond differently than men? *Journal of Applied Physiology, 99*(5), 1712-1718.

de Vos, N. J., Singh, N. A., Ross, D. A., Stavrinos, T. M., Orr, R., & Fiatarone Singh, M. A., (2005). Optimal load for increasing muscle power during explosive resistance training in older adults. *Journals of Gerontology: Medical Sciences, 60A*(5), 638-647.

Earles, D. R., Judge, J. O., & Gunnarsson, O. T. (2001). Velocity training induces power-specific adaptations in highly functioning older adults. *Archives of Physical Medicine and Rehabilitation, 82*(7), 872-878.

Ferri, A., Scaglioni, G., Pousson, M., Capodaglio, P., Van Hoecke, J., & Narici, M. V. (2003). Strength and power changes of the human plantar flexors and knee extensors in response to resistance training in old age. *Acta Physiologica Scandinavica, 177*(1), 69-78.

Fiatarone, M. A., Marks, E. C., Ryan, N. D., Meredith, C. N., Lipsitz, L. A., & Evans, W. J. (1990). High-intensity strength training in nonagenarians. *Journal of the American Medical Association, 263*(22), 3029-3034.

Fiatarone, M. A., O'Neil, E. F., Doyle Ryan, N., Clement, s. K., Solares, G. R., Nelson, M. E., et al. (1994). Exercise training and nutritional supplementation for physical frailty in very elderly people. *The New England Journal of Medicine, 330*(25), 1769-1775.

Fielding, R. A., LeBrasseur, N. K., Cuoco, A., Bean, J., Mizer, K., & Fiatarone Singh, M. A. (2002). High velocity power training increases skeletal muscle peak power in older women. *Journal of the American Geriatrics Society, 50*(4), 655-662.

Foldvari, M., Clark, M., Laviolette, L. C., Bernstein, M. A., Kaliton, D., Castaneda, C., et al. (2000). Association of muscle power with functional status in community-dwelling elderly women. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 55A*(4), M192-M199.

Hakkinen, K., Alen, M., Kallinen, M., Newton, R. U., & Kraemer, W. J. (2000). Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. *European Journal of Applied Physiology, 83*(1), 51-62.

Hakkinen, K., Newton, R. U., Gordon, S. E., McCormick, M., Volek, J. S., Nindl, B. C., et al. (1998b). Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 53A*(6), B415-B423.

Hakkinen, K., Pakarinen, A., Kraemer, W. J., Hakkinen, A., Valkeinen, H., & Alen, M. (2001b). Selective muscle hypertrophy, changes in emg and force, and serum hormones during strength training in older women. *Journal of Applied Physiology, 91*(2), 569-580.

Henwood, T. R., & Taaffe, D. R. (2005). Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. *Gerontology, 51*(2), 108-115.

Hruda, K. V., Hicks, A. L., & McCartney, N. (2003). Training for muscle power in older adults: Effects on functional abilities. *Canadian Journal of Applied Physiology, 28*(2), 178-189.

Izquierdo, M., Aguado, X., Gonzalez, R., Lopez, J. L., & Hakkinen, K. (1999). Maximal and explosive force production capacity and balance performance in men of different ages. *European Journal of Applied Physiology, 79*(3), 260-267.

Izquierdo, M., Hakkinen, K., Ibanez, J., Garrues, M., Anton, A., Zuniga, A., et al. (2001). Effects of strength training on muscle power and serum hormones in middle-aged and older men. *Journal of Applied Physiology, 90*(4), 1497-1507.

Jozi, A. C., Campbell, W. W., Joseph, L., Davey, S. L., & Evans, W. J. (1999). Changes in power with resistance training in older and younger men and women. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 55A*(11), M591-M596.

Kaneko, M., Fuchimoto, T., Toji, H., & Suei, K. (1983). Training effect of different loads on the force-velocity relationship and mechanical power output in human muscle. *Scandinavian Journal of Sports Science, 5*(2), 50-55.

Labarque, V., T Eunde, B. O., & Van Leemputte, M. (2002). Resistance training alters torque-velocity relation of elbow flexors in elderly men. *Medicine and Science in Sports and Exercise, 34*(5), 851-856.

Lukaski, H. C., Bolunchuk, W. W., Hall, C. B., & Siders, W. A. (1986). Validation of tetrapolar bioelectrical impedance method to assess human body composition. *Journal of Applied Physiology, 60*(4), 1327-1332.

Macaluso, A., & De Vito, G. (2003). Comparison between young and older women in explosive power output and its determinants during a single leg-press action after optimisation of load. *European Journal of Applied Physiology, 90*(5-6), 458-463.

Macaluso, A., Young, A., Gibb, K. S., Rowe, D. A., & De Vito, G. (2003). Cycling as a novel approach to resistance training increases muscle strength, power, and selected functional abilities in healthy older women. *Journal of Applied Physiology, 95*(6), 2544-2553.

Metter, E. J., Conwit, R., Tobin, J., & Fozard, J. L. (1997). Age-associated loss of power and strength in the upper extremities in women and men. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 52A*(5), B267-B276.

Miszko, T. A., Cress, E., Slade, J. M., Covey, C. J., Agrawal, S. K., & Doerr, C. E. (2003). Effect of strength and power training on physical function in community-dwelling older adults. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 58A*(2), 171-175.

Orr, R., de Vos, N. J., Singh, N. A., Ross, D. A., Stavrinos, T. M., & Fiatarone Singh, M. A. (2006). Power training improves balance in healthy older adults. *Journal of Gerontology: Medical Sciences, 61A*(1), 78-85.

Reeves, N. D., Maganaris, C. N., & Narici, M. V. (2003). Strength training alters the viscoelastic properties of tendons in elderly humans. *Muscle and Nerve, 28*(1), 74-81.

Roubenoff, R., Baumgartner, R. N., Harris, T. B., Dallal, G. E., Hannan, M. T., Economos, C. D., et al. (1997). Application of bioelectrical impedance analysis to elderly populations.

Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 52A(3), M129-M136.

Sayers, S. P., Guralnik, J. M., Thombs, L. A., & Fielding, R. A. (2005). Effect of leg muscle contraction velocity on functional performance in older men and women. *Journal of the American Geriatrics Society, 53*(3), 467-471.

Singh, N. A., Clements, K. M., & Fiatarone, M. A. (1999). A randomized controlled trial of progressive resistance training in depressed elders. *J Gerontol Med Sci, 52A*(1), M27-M35.

Skelton, D. A., Greig, C. A., Davies, J. M., & Young, A. (1994). Strength, power and related functional ability of healthy people aged 65-89 years. *Age and Ageing, 23*(5), 371-377.

Suzuki, T., Bean, J. F., & Fielding, R. A. (2001). Muscle power of the ankle flexors predicts functional performance in community-dwelling older women. *Journal of the American Geriatrics Society, 49*(9), 1161-1167.

Taaffe, D. R., Duret, C., Wheeler, S., & Marcus, R. (1999). Once-weekly exercise improves muscle strength and neuromuscular performance in older adults. *Journal of the American Geriatrics Society, 47*(10), 1208-1214.

Thomas, M., Fiatarone, M. A., & Fielding, R. A. (1996). Leg power in young women: Relationship to body composition, strength, and function. *Medicine and Science in Sports and Exercise, 28*(10), 1321-1326.

Wickiewicz, T. L., Roy, R. R., Powell, P. L., Perrine, J. J., & Edgerton, V. R. (1984). Muscle architecture and force-velocity relationships in humans. *Journal of Applied Physiology, 57*(2), 435-443.

TABLES

Table 1 – Participant Characteristics

Characteristic	Total *(N = 112)*	G80 *(N = 28)*	G50 *(N = 28)*	G20 *(N = 28)*	CON *(N = 28)*	*p*
Age (years)	68.5 (5.7)	69.0 (6.4)	68.1 (4.5)	69.4 (5.8)	67.6 (6.0)	.63
% Men	39	39	39	39	39	
Body Weight (kg)	71.4 (12.4)	71.1 (13.1)	72.4 (12.6)	71.9 (14.2)	70.4 (13.3)	.95
Height (cm)	165.5 (9.2)	165.1 (11.0)	165.1 (6.9)	165.3 (10.6)	166.7 (7.9)	.90
Body-Mass Index (kg/m^2)	26 (3.6)	26 (3.3)	26.5 (3.9)	26.2 (3.7)	25.2 (3.8)	.62
Fat Free Mass (kg)*	46.3 (9.8)	46.7 (10.3)	46.7 (9.0)	45.8 (10.3)	46.2 (9.9)	.98
Body Fat (kg)	25.1 (7.5)	24.4 (6.4)	25.7 (8.2)	26.1 (8.6)	24.2 (6.9)	.72
Regular Medications (no./day)	1 (0-7)	1 (0-7)	1 (0-7)	1 (0-6)	1 (0-6)	.95
Medical Diagnoses (no.)	1 (0-4)	1 (0-4)	1 (0-3)	0.5 (0-3)	1 (0-4)	.77
Fallers (%)†	21	11	32	21	21	.28

Notes: Values of normally distributed data are presented as means (SD). Skewed data are presented as medians and ranges. G80 = high intensity (80% 1RM) group, G50 = medium intensity (50% 1RM) group, G20 = low intensity (20% 1RM) group, CON = control group. *Fat free mass was determined using bioelectrical impedance analysis (Lukaski et al., 1986). † "Fallers" refers to the percentage of participants who had 1 or more falls in the past 12 months. P values determined by Chi-square for Fallers, Kruskal-Wallis ANOVA for Regular Medications and Medical diagnosis, and factorial ANOVA for others. A *P*-value of < 0.05 was accepted as statistically significant.

Table 2 – Baseline Performance Measures

Characteristic	Total *(N = 112)**	G80 *(N = 28)*	G50 *(N = 28)*	G20 *(N = 28)*	CON *(N = 28)*	*P*
%1RM at peak power						
Leg press	62 ± 8	61 ± 7	60 ± 6	61 ± 9	64 ± 7	.13
Chest press	56 ± 6	57 ± 6	55 ± 7	55 ± 5	57 ± 5	.62
Knee extension	75 ± 9	75 ± 9	74 ± 9	74 ± 10	78 ± 7	.28
Seated row	78 ± 7	80 ± 5	79 ± 8	77 ± 7	75 ± 10	.06
Knee flexion	61 ± 8	60 ± 10	59 ± 8	62 ± 5	63 ± 8	.49
Average %1RM at peak power†	66 ± 4	67 ± 4	65 ± 4	66 ± 5	67 ± 3	.24
Force at peak power (FPP)						
Leg press, N	677 ± 232	714 ± 237	652 ± 220	613 ± 206	685 ± 244	.35
Chest press, N	156 ± 67	169 ± 52	170 ± 59	136 ± 52	152 ± 57	.12
Knee extension, Nm	101 38	109 ± 43	100 ± 35	89 ± 31	104 ± 38	.32
Seated row, N	179 ± 77	185 ± 68	185 ± 61	165 ± 67	174 ± 59	.17
Knee flexion, Nm	84 ± 27	85 ± 28	81 ± 21	78 ± 25	86 ± 27	.60
Total FPP‡	1200 ± 298	1238 ± 392	1170 ± 356	1077 ± 363	1195 ± 416	.57
Velocity at peak power (VPP)						
Leg press, cm/s	75 ± 11	71 ± 12	78 ± 7	73 ± 9	74 ± 12	.27
Chest press, cm/s	98 18	95 ± 19	101 ± 17	94 ± 19	97 ± 16	.69
Knee extension, rad/s	2.47 ± 0.42	2.36 ± 0.35	2.61 ± 0.45	2.41 ± 0.42	2.44 ± 0.40	.42
Seated row, cm/s	159 ± 25	163 ± 23	156 ± 28	154 ± 25	160 ± 26	.66
Knee flexion, rad/s	3.02 ± 0.45	2.98 ± 0.47	3.09 ± 0.39	2.93 ± 0.46	3.01 ± 0.50	.47
Total VPP‡	338 ± 46	329 ± 44	335 ± 44	325 ± 45	338 ± 45	.74
Average FPP/VPP†	16.4 ± 5.1	17.4 ± 5.5	15.6 ± 3.6	15.4 ± 5.8	17.1 ± 5.4	.38

Notes: Values are presented as means ± SD. G80 = high intensity (80% 1RM) group, G50 = medium intensity (50% 1RM) group, G20 = low intensity (20% 1RM) group, CON = control group. *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. FFM = fat-free mass. Factorial ANOVA was used to analyze differences between groups at baseline. A *P* value of <.05 was accepted as statistically significant.

Table 3 – Univariate Associations with Average Percentage Change in Peak Power

Group	Variable	r	P-Value
G80 (n = 20)	FFM (% change)	0.574	**0.008**
	Force at peak power (average % change)	0.52	**0.019**
	Velocity at peak power (average % change)	0.132	0.580
G50 (n = 20)	FFM (% change)	0.328	0.153
	Force at peak power (average % change)	0.655	**0.002**
	Velocity at peak power (average % change)	0.232	0.325
G20 (n = 24)	FFM (% change)	0.218	0.306
	Force at peak power (average % change)	0.488	**0.016**
	Velocity at peak power (average % change)	0.276	0.192

Notes: G80 = high intensity (80% 1RM) group, G50 = medium intensity (50% 1RM) group, G20 = low intensity (20% 1RM) group. FFM = fat-free mass. Bold type indicates $P<.05$.

FIGURE LEGENDS

Figure 1: Average change in %1RM at peak power (▨), and average percentage change in force at peak power (■), and velocity at peak power (□), after explosive resistance training in older adults. Values are mean ± standard deviation averaged across the 5 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. Fisher protected-least-significant-difference post hoc comparisons revealed: * significantly greater than CON (*P*<.001).

Figure 2: Change in FPP/VPP ratio after explosive resistance training in older adults. Values are mean ± standard deviation averaged across the 5 exercises. G80 = high intensity (80% 1RM) group; G50 = medium intensity (50% 1RM) group; G20 = low intensity (20% 1RM) group; CON = control group. ANCOVA model was adjusted for baseline value. Fisher protected-least-significant-difference post hoc comparisons revealed: * significantly greater than CON (*P*>.03).

FIGURES

Figure 1:

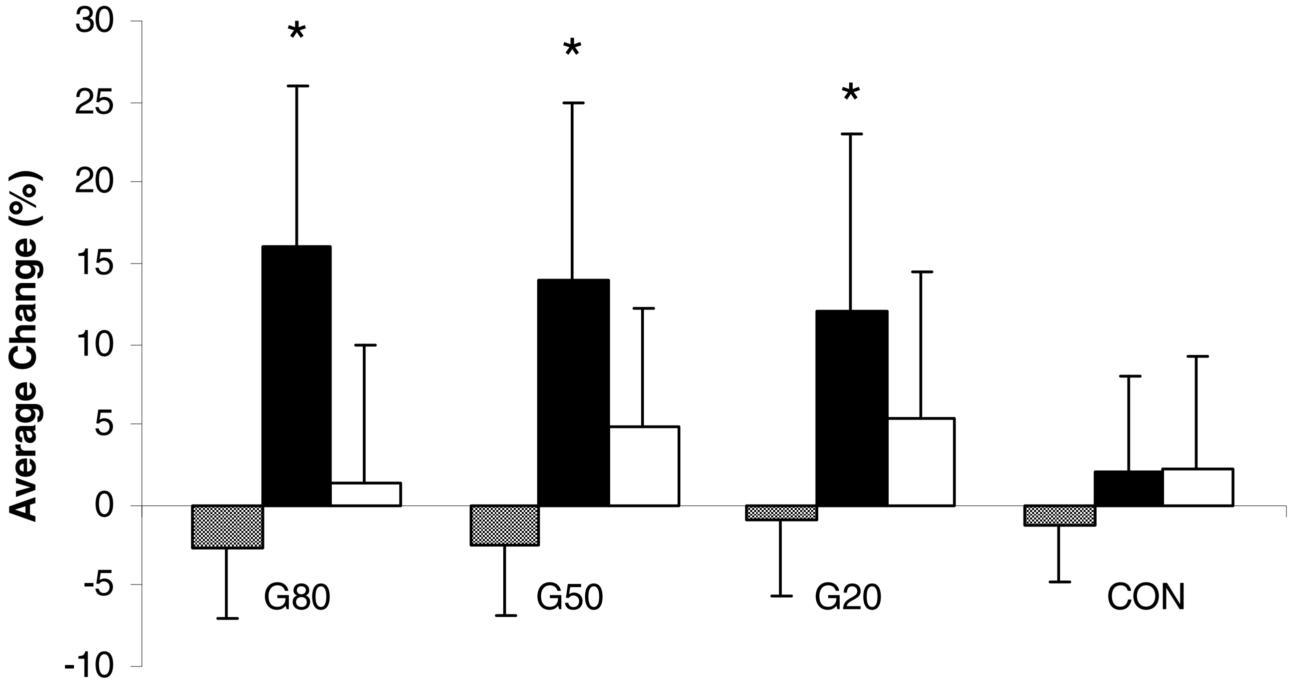

Figure 2: