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Optimal Load for Increasing Muscle Power During Explosive Resistance Training in Older Adults

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Background. Muscle power (force × velocity) recedes at a faster rate than strength with age and may also be a stronger predictor of fall risk and functional decline. The optimal training paradigm for improving muscle power in older adults is not known, although some literature suggests high velocity, low load training is optimal in young adults.

Methods. One hundred twelve healthy older adults (69 ± 6 years) were randomly assigned to either explosive resistance training at 20% (G20), 50% (G50), or 80% (G80) one repetition maximum (1RM) for 8–12 weeks or to a nontraining control group (CON). Participants trained twice per week (five exercises; three sets of eight rapidly concentric and slow eccentric repetitions) using pneumatic resistance machines. Repeated-measures analysis of variance and covariance (ANOVA and ANCOVA) were used to determine the effects of training.

Results. Average peak power increased significantly and similarly in G80 (14 ± 8%), G50 (15 ± 9%), and G20 (14 ± 6%) compared to CON (3 ± 6%) ($p < .0001$). By contrast, a positive dose-response relationship with training intensity was observed for relative changes in average strength ($r = .40$, $p = .0009$) and endurance ($r = .43$, $p = .0005$). Average strength increased in G80 (20 ± 7%), G50 (16 ± 7%), and G20 (13 ± 7%) compared to CON (4 ± 4%) ($p < .0001$). Average muscle endurance increased in G80 (185 ± 126%, $p < .0001$), G50 (103 ± 75%, $p = .0004$), and G20 (82 ± 57%, $p = .0078$) compared to CON (28 ± 29%).

Conclusion. Peak muscle power may be improved similarly using light, moderate, or heavy resistances, whereas there is a dose-response relationship between training intensity and muscle strength and endurance changes. Therefore, using heavy loads during explosive resistance training may be the most effective strategy to achieve simultaneous improvements in muscle strength, power, and endurance in older adults.

A predictable accompaniment to natural aging beyond the fourth to fifth decade of life is a steady reduction in the force-generating capacity, or strength, of the skeletal muscles (1–5). Age-associated losses in strength occur predominately as a consequence of reductions in muscle cross-sectional area (4,6). However, loss of muscle power, the product of muscular force and velocity of contraction, does not mirror, but exceeds the rate of strength loss with age (1–3,5). Preferential atrophy of type II muscle fibers (7,8), which possess a twofold to fourfold greater contraction velocity than do type I muscle fibers (9,10), may partially explain the discrepancy between losses in strength and power with age.

Muscle power has been shown to be positively associated with the ability in older adults to perform activities of daily life such as walking, rising from a chair, and climbing stairs (11–13), and may be a stronger predictor of functional dependency than is muscle strength (11,13–17). Muscle power is also related to dynamic balance (13) and postural sway (5), and may be a stronger predictor of fall risk than is strength (18,19). Thus increases in muscle power may lead to improvements in functional capacity and prevent falls, dependency, and disability in later life.

Relatively few studies have been specifically designed to increase muscle power in older adults. Most studies use traditional high intensity, slow velocity resistance-training protocols for the purpose of increasing strength, which may yield disproportionately lower power gains (20–23), thus warranting more specific training strategies to improve muscle power in older adults (15). Explosive or high-velocity resistance training is a form of power training, the intent of which is to perform maximal velocity concentric muscle contractions against an external resistance without projection of the load into free space, as occurs with other methods of power training such as ballistic training or plyometrics (24). Previous studies (7,25–31) have demonstrated the efficacy of explosive resistance training in older adults.

The current recommendation for improving muscle power in healthy older adults is a combined strategy incorporating traditional (slow) high-intensity (60%–80% of one-repetition maximum [1RM]) resistance training together with light-to-moderate explosive resistance training (40%–60% 1RM) (32). However, the optimal training intensity to use during explosive resistance training in older adults has not been examined. Speculation exists as to whether the optimal training intensity is the same as that used to generate instantaneous peak power. Studies using younger subjects (33–35) have reported peak power generation at loads equivalent to 30% of maximum strength. Conversely, studies including older adults (6,13,16,36) have found peak power generated at a broader range of higher intensities

(~50%–80% 1RM). This study has, for the first time to our knowledge, addressed the issue of power training intensity by conducting a systematic dose-response investigation into the optimal load for maximizing gains in muscle power in older adults. It was our hypothesis that explosive resistance training using heavy loads (80% 1RM) would deliver muscle power and strength improvements superior to training using lighter loads (20% or 50% 1RM).

Methods

Study Design

This was a controlled trial in which participants were randomly assigned either to a low-, medium-, or high-intensity training group or to a nontraining control group. Participants in the training groups were blinded to the investigators' hypothesis as to which training intensity was optimal. The duration of the study was originally 8 weeks, but later extended to 12 weeks due to additional resource availability.

Study Population

Recruitment and screening.—Participants were recruited through advertisements, distribution of flyers, and presentations to senior groups. Screening stages included a telephone questionnaire followed by resting electrocardiogram, medical history, and physical examination. Inclusion criteria included: age ≥60 years, living independently in the community, and willingness to be randomized and to commit to the study requirements. Exclusion criteria included: participation in resistance- and/or power-training exercise within the past 6 months (≥1 time per 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 provided 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 enrollment. 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) (37,38).

Dynamic muscle strength testing.—Dynamic muscle strength (1RM) was assessed on digital Keiser pneumatic resistance machines fitted with A400 electronics (Keiser Sports Health Equipment, Fresno, CA) using the 1RM in five exercises: bilateral horizontal leg press, seated chest press, bilateral leg extension, seated row, and seated bilateral leg curl. The 1RM is defined as the maximum load that can be lifted once throughout the full range of motion while maintaining correct technique. Each participant's full range of motion was determined during performance of a minimally loaded repetition prior to each test. Measurements of 1RM were repeated weekly throughout the training program for participants randomized to the three training groups. Total strength was calculated by summing the 1RM values obtained in each of the five exercises.

Muscle power testing.—After 30 minutes of rest following measurement of 1RM, peak muscle power (W) was assessed at 10 relative intensities (20%, 40%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, and 85% 1RM) on the same five pneumatic resistance machines used for the strength testing. 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 at a rate of 400 times per second. The total work (J) was computed from data collected between the start and finish of the concentric phase of the repetition. Power was calculated as the average power between 5% and 95% of the concentric phase to eliminate fluctuations at the beginning and end points of motion. The highest mean power produced throughout the loads tested was recorded as the peak power. The loads used to assess final power after the intervention were relative to the final 1RM, not the baseline 1RM. Total power was calculated by summing the peak power values obtained in each of the five exercises.

Muscle endurance testing.—After a 30-minute rest following power testing, muscle endurance was assessed on the same five pneumatic resistance machines used for the strength and power testing. For baseline and final testing, the load was set at 90% of baseline 1RM. Participants were instructed to perform, using good form, as many slow consecutive repetitions as possible through their full range of motion, with no rest between repetitions. Average endurance was calculated by summing the repetitions achieved in each of the five exercises and dividing the sum by five.

Training Intervention

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. Four slow consecutive repetitions at approximately half of the participant's prescribed training weight for each exercise were performed to serve as a specific neuromuscular warm-up and psychological preparation. On the first training day of each week (Tuesdays), three sets of eight repetitions were performed. On the second training day of each week (Thursdays) a 1RM test was performed, followed by two sets of eight repetitions. Resistance was increased throughout the study relative to the participant's best 1RM. The first two training sessions for G80 were performed at 50% and 70% 1RM to help reduce the severity of muscle soreness and to better the participants' execution of the exercises before progressing to train with heavier loads. Participants were instructed to perform the concentric phase of each repetition as rapidly as possible and to perform each eccentric phase over 3 seconds. All training sessions were directly supervised by experienced exercise trainers, and each repetition was verbally cued ''1, 2, 3, GO!'' as during power testing. Participants rested 10–15 seconds between repetitions and alternated exercises after each set. Training was performed in mixed groups (i.e., G20, G50, and G80 together) of up to five participants.

Participants in the control group (CON) did not undergo any training or weekly strength testing. CON participants were instructed to maintain their current level of physical activity for the duration of the study, and were offered a home-based resistance-training program upon completion of final testing.

Changes in medication, health status, psychological well-being, occurrence of falls, and bodily pain were monitored in all participants by using a weekly questionnaire administered either by telephone or in person.

Statistical Analysis

All statistical procedures were performed using the StatView statistical software package (Abacus Concepts, Berkeley, CA). Computer-generated randomization plans (39) 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. Linear regression was used to reveal pertinent relationships between variables at baseline, and between changes in outcome variables following the intervention. Repeated measures ANOVA and analysis of covariance (ANCOVA) were used to analyze the effects of training intensity on outcome variables over time and to identify any group-by-time interactions. Fisher's protected-least-significant-difference post hoc *t* tests were used to identify source of differences. Statistical significance was accepted at $p < .05$.

Results

Recruitment Progression

Participant screening and flow throughout the study are presented in Figure 1. Of those participants who were screened out, 123 were due to nonmedical exclusions and 143 were due to medical exclusions (musculoskeletal pain [84], unstable cardiovascular condition [16], nervous system disorder [11], terminal and/or rapidly progressive disease [6], retinal detachment [8], symptomatic hernia [9], bladder prolapse [3], recent fracture [1], steroid injections [4], or deceased since screening [1]). Therefore, 29% (112) of the original respondents were eligible and randomized.

Attrition, Compliance, and Training Duration

Twelve participants (11%) dropped out of the study. One participant from each training group experienced joint pain probably related to testing/training. One participant sustained an inguinal hernia during strength testing. The reasons for the rest of the dropouts (8) were not related to the intervention (see Figure 1).

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 ($p = .12$).

Thirty-nine of 41 (95%) participants randomized to 8 weeks and 61 of 71 (86%) participants randomized to 12 weeks completed the intervention and proceeded to final testing. The average study duration for all participants was 10 ± 2 weeks, with no difference between groups ($p = .98$). The average time of dropout was 6 ± 4 weeks. Participants who dropped out did not return for final testing and are not included in the final statistical analysis.

Participant Demographic and Baseline Characteristics

Baseline characteristics are presented in Table 1. Baseline performance measures for each exercise are presented in Table 2. There were no differences between groups in any characteristic or performance variable at baseline. Baseline values were used as covariates in ANCOVA models when analyzing each outcome variable.

Training Intensity

Relative training load achieved closely approximated the prescribed intensity for each group throughout the study (see Figure 2).

Adverse Events

Among the 112 participants randomized, there were 20 adverse events reported in 17 participants (15%). Sixteen reports (80%) were related to strength testing, whereas four (20%) were related to power training. There were 4711 strength tests conducted and 1633 power-training sessions held, making the rate of adverse events 0.34% and 0.25% for strength testing and power training, respectively. Eight (40%) adverse events were reported in G80; seven (35%) in G50; four (20%) in G20; and one (5%) in CON. The four adverse events related to power training occurred in G80. Most adverse events were musculoskeletal in nature such as minor strains (50%), tendonitis (30%), and exacerbation of osteoarthritis (15%), all of which resolved with alterations in training regimens or anti-inflammatory and/or analgesic medication. One participant sustained an inguinal hernia subsequent to strength testing that required surgical repair. No cardiovascular complications occurred during any testing or training sessions.

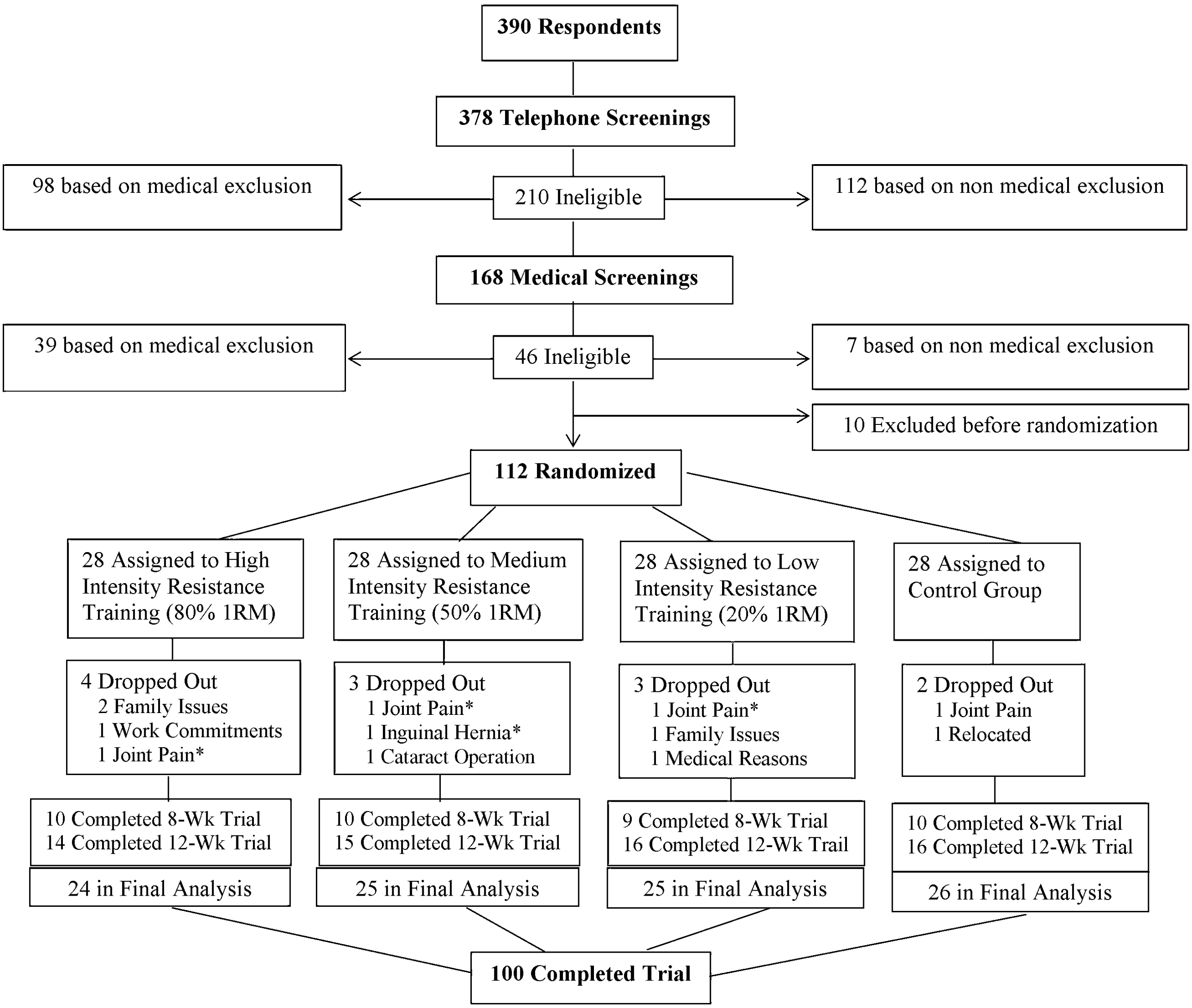

Figure 1. Participant flow from initial respondents to study completion. *Drop-outs related to training and/or testing.

Primary Outcomes

Peak muscle power.—Peak muscle power increased significantly in each exercise across all groups ($p <$ .0001) (Table 3). Significant group-by-time interactions also occurred for each exercise ($p = .0156$ to .0002) after the intervention. Total peak power increased 214 ± 120 W, 237 ± 145 W, 168 ± 109 W, and 42 ± 91 W in G80, G50, G20, and CON, respectively ($p < .0001$). Average percentage improvements in peak power were 14 ± 8%, 15 ± 9%, 14 ± 7%, and 3 ± 6% in G80, G50, G20, and CON, respectively (Figure 3A). There was no difference between training intensities in the average percentage of improvement ($p = .8540$ to .4397). All training groups made significantly greater absolute and relative improvements than did controls ($p < .0001$). Absolute changes in total peak power were greater in G50 than in G20 ($p = .0239$), with G80 improving similarly to G50 ($p = .4537$) and G20 ($p = .1330$). Average percentage changes in peak power were related to baseline body fat ($r = .234$, $p = .0274$) and percentage changes in fat-free mass ($r = .344$, $p = .001$).

Muscle strength.—Absolute and relative changes in muscle strength appear in Table 3. For each exercise, there were significant time ($p < .0001$) and group effects ($p <$ .0001 to .0012). Total strength increased 335 ± 154 N, 295 ± 182 N, 219 ± 106 N, and 69 ± 111 N in G80, G50, G20, and CON, respectively ($p < .0001$). Average percentage improvements in strength were 20 ± 7%, 16 ± 7%, 13 ± 7%, and 4 ± 4% in G80, G50, G20, and CON, respectively (Figure 3B). All training groups made significantly greater absolute and relative improvements than did controls ($p < .0001$). There was a significant dose-response relationship between training intensity and average relative strength improvement ($r = .40$, $p = .0009$), with G80 improving more than G50 ($p = .0448$) and G20 ($p = .0001$),

Table 1. Baseline Participant Characteristics

Characteristic	Total (N = 112)	G80 (N = 28)	G50 (N = 28)	G20 (N = 28)	CON (N = 28)	p
Age, y	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	71.44 (12.42)	71.06 (13.08)	72.38 (12.61)	71.89 (14.21)	70.43 (13.28)	.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	46.32 (9.77)	46.65 (10.26)	46.64 (9.04)	45.76 (10.28)	46.22 (9.94)	.98
Body fat, kg	25.12 (7.51)	24.41 (6.41)	25.74 (8.18)	26.13 (8.54)	24.21 (6.92)	.72
Regular medications, No./d	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 (standard deviation). Skewed data are presented as medians and ranges. G80 = High-intensity (80% one repetition maximum [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. ''Fallers'' refers to the percentage of participants who had 1 or more falls in the past 12 months. p values were determined by chi square for fallers, Kruskal–Wallis analysis of variance (ANOVA) for regular medications and medical diagnosis, and factorial ANOVA for others. A p value of $< .05$ was accepted as statistically significant.

and G50 improving more than G20 ($p = .0445$). Average percentage changes in strength were related to percentage changes in fat-free mass ($r = .287$, $p = .0055$).

Muscle endurance.—Significant time effects and group-by-time interactions were found for muscle endurance in each exercise ($p < .0001$) (Table 3). Average endurance increased seven (185 ± 126%, $p < .0001$), five (103 ± 75%, $p = .0001$), and three (82 ± 57%, $p = .0032$) repetitions in G80, G50, and G20, respectively, compared to one (26 ± 29%) repetition in CON (Figure 3C). There was a significant dose-response relationship between training intensity and improvements in average muscle endurance ($r = .43$, $p = .0005$). Gains in G80 were greater than those in G50 ($p = .0001$) and G20 ($p < .0001$), but were similar between G50 and G20 ($p = .2666$). Average percentage changes in endurance were inversely related to baseline average endurance ($r = -.382$, $p = .0002$).

Secondary Outcomes

Body composition.—No significant changes occurred in body weight, height, body mass index, body fat, or fat-free mass (data not shown).

Table 2. Baseline Performance Measures

Characteristic	Total (N = 112)*	G80 (N = 28)	G50 (N = 28)	G20 (N = 28)	CON (N = 28)	p
Muscle power						
Leg press, W	649 ± 241	668 ± 259	671 ± 246	611 ± 219	647 ± 248	.78
Chest press, W	196 ± 86	208 ± 87	208 ± 89	177 ± 84	191 ± 86	.50
Leg extension, W	286 ± 119	290 ± 128	302 ± 123	264 ± 118	288 ± 109	.69
Seated row, W	335 ± 141	353 ± 157	335 ± 133	319 ± 143	334 ± 135	.84
Leg flexion, W	238 ± 80	247 ± 89	242 ± 70	220 ± 70	242 ± 89	.60
Total peak power, W†	1708 ± 643	1786 ± 697	1758 ± 630	1584 ± 615	1701 ± 644	.67
Muscle strength						
Leg press, N	1112 ± 394	1190 ± 432	1121 ± 363	1057 ± 395	1079 ± 391	.61
Chest press, N	281 ± 103	299 ± 106	299 ± 106	256 ± 98	269 ± 101	.30
Leg extension, Nm	135 ± 48	141 ± 53	139 ± 45	124 ± 46	136 ± 47	.55
Seated row, N	230 ± 83	232 ± 90	230 ± 70	224 ± 93	234 ± 82	.98
Leg flexion, Nm	138 ± 44	145 ± 52	139 ± 37	130 ± 46	137 ± 43	.69
Total strength†	1899 ± 644	2024 ± 702	1928 ± 597	1791 ± 646	1854 ± 639	.58
Muscle endurance						
Leg press, reps	11 ± 6	10 ± 6	12 ± 6	12 ± 7	12 ± 6	.37
Chest press, reps	5 ± 2	5 ± 2	6 ± 2	5 ± 2	5 ± 2	.15
Leg extension, reps	4 ± 2	4 ± 2	4 ± 2	3 ± 2	4 ± 2	.24
Seated row, reps	6 ± 3	7 ± 3	7 ± 3	5 ± 3	5 ± 2	.25
Leg flexion, reps	5 ± 3	5 ± 2	5 ± 2	6 ± 3	5 ± 2	.52
Average endurance‡	6 ± 2	6 ± 2	7 ± 2	6 ± 2	7 ± 2	.31

Notes: Values are presented as means ± standard deviation. G80 = high-intensity (80% one-repetition maximum [1RM]) group; G50 = medium-intensity (50% 1RM) group; G20 = low-intensity (20% 1RM) group; CON = control group.

*n = 110 for chest press exercise: One participant from G80 and one from G20 were excluded from performing this exercise.

†Total peak power and total strength (n = 110) = summed value of the five exercises.

‡Average endurance (n = 110) = average number of repetitions across the five exercises. Factorial analysis of variance was used to analyze differences between groups at baseline. A p value of <.05 was accepted as statistically significant.

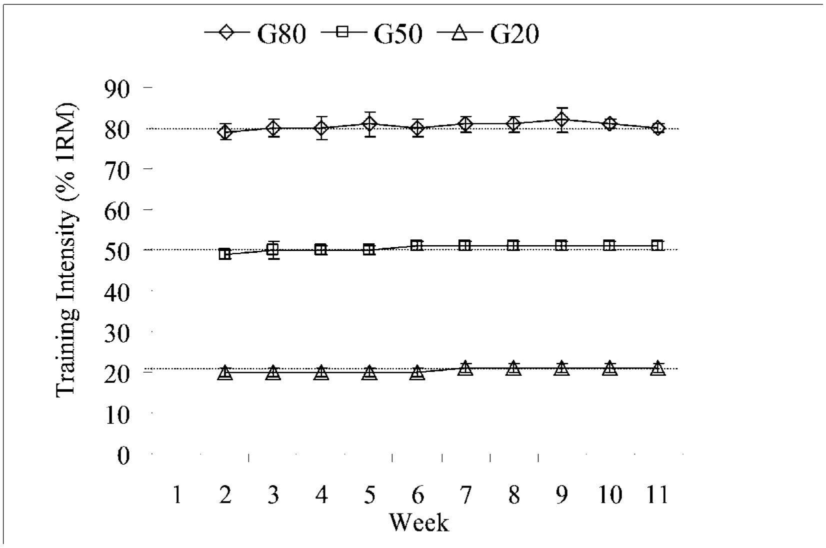

Figure 2. Average weekly training intensity during explosive resistance training. The actual training intensity for each training group across five exercises remained very close to the prescribed intensity. G80 = high-intensity (80% 1RM) group; G50 = medium-intensity (50% 1RM) group; G20 = low-intensity (20% 1RM) group.

Discussion

Muscle Power

Training using loads of 20%, 50%, or 80% of the 1RM during explosive resistance training produced similar percentage gains in peak muscle power in healthy older adults (Table 3, Figure 3A). Although not the hypothesized outcome, this finding is similar to those from previous studies showing that muscle power may be improved using a variety of intensities. For example, improvements in peak power or rate of force development after explosive resistance training have been demonstrated using light

Table 3. Absolute and Relative Changes in Muscle Peak Power, Strength, and Endurance

Outcome Variable	Number of Subjects	G80	G50	G20	CON	*p*: Time Effect	*p*: Group-by-Time Interaction
Muscle power							
Leg press, W	97	69 ± 53* (12 ± 11)*	85 ± 60* (14 ± 9)*	51 ± 72* (9 ± 13)*	11 ± 46 (2 ± 8)	<.0001	0.0002
Chest press, W	94	19 ± 20* (11 ± 13)*	18 ± 19* (8 ± 8)*	17 ± 16* (13 ± 12)*	3 ± 14 (2 ± 7)	<.0001	0.0027
Leg extension, W	97	42 ± 34* (14 ± 13)*	47 ± 45* (18 ± 16)*	30 ± 25 (14 ± 13)*	13 ± 19 (5 ± 7)	<.0001	0.0016
Seated row, W	98	29 ± 40* (9 ± 11)	34 ± 41* (14 ± 24)*	28 ± 20* (11 ± 8)*	6 ± 27 (2 ± 9)	<.0001	0.0145
Leg flexion, W	96	41 ± 32* (19 ± 16)*	42 ± 31* (17 ± 12)*	43 ± 33* (21 ± 14)*	9 ± 34 (4 ± 14)	<.0001	0.0007
Muscle strength							
Leg press, N	98	169 ± 116* (15 ± 9)*	169 ± 142* (16 ± 13)*	146 ± 86* (16 ± 11)*	45 ± 102 (4 ± 7)	<.0001	0.0003
Chest press, N	94	39 ± 22*† (15 ± 10)*†	33 ± 31* (11 ± 10)*	22 ± 17* (9 ± 8)*	9 ± 13 (3 ± 4)	<.0001	0.0001
Leg extension, Nm	97	36 ± 24*† (27 ± 16)*†	30 ± 17*† (23 ± 12)*	19 ± 16* (16 ± 13)*	4 ± 13 (5 ± 9)	<.0001	<.0001
Seated row, N	98	56 ± 39*† (24 ± 13)*†	45 ± 24*† (20 ± 10)*†	25 ± 21* (13 ± 10)*	5 ± 14 (2 ± 6)	<.0001	<.0001
Leg flexion, Nm	98	23 ± 11*†‡ (17 ± 8)*†	16 ± 14* (12 ± 10)*	11 ± 11 (11 ± 15)*	6 ± 8 (5 ± 6)	<.0001	<.0001
Muscle endurance							
Leg press, reps	95	13 ± 12*†‡ (286 ± 410)*†‡	7 ± 5 (121 ± 275)	4 ± 6 (82 ± 143)	3 ± 6 (27 ± 45)	<.0001	0.0002
Chest press, reps	94	6 ± 3*†‡ (132 ± 80)*†‡	3 ± 3* (70 ± 89)*	3 ± 3* (62 ± 86)*	1 ± 1 (20 ± 29)	<.0001	<.0001
Leg extension, reps	97	3 ± 1*† (109 ± 107)*	3 ± 3* (99 ± 91)*	2 ± 2* (78 ± 73)*	0 ± 2 (11 ± 59)	<.0001	<.0001
Seated row, reps	98	8 ± 5*† (149 ± 112)*	6 ± 5* (117 ± 86)*	4 ± 4* (102 ±122)*	2 ± 3 (31 ± 59)	<.0001	<.0001
Leg flexion, reps	97	6 ± 4*† (244 ± 366)*†‡	5 ± 3*† (115 ± 100)	3 ± 2 (76 ± 104)	1 ± 2 (43 ± 68)	<.0001	<.0001

Notes: Values are presented as means ± standard deviation. Percentage changes are in parentheses. G80 = High-intensity (80% one-repetition maximum [1RM]) group; G50 = medium-intensity (50% 1RM) group; G20 = low-intensity (20% 1RM) group; CON = control group. Repeated measures analysis of variance was used to analyze time effects and group-by-time interactions. Analysis of covariance (ANCOVA) was performed on absolute and relative change adjusted for baseline value of each variable. Fisher's protected-least-significant-difference post hoc *t* test was performed on ANCOVA to identify the source of differences.

*Significantly greater than CON.

†Significantly greater than G20.

‡Significantly greater than G50.

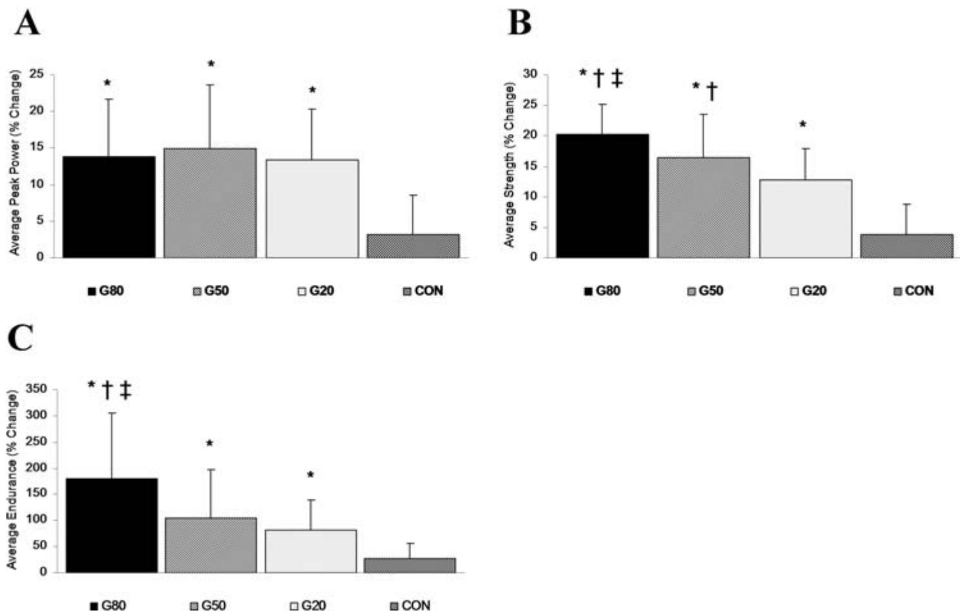

Figure 3. Average change in peak power (**A**), strength (**B**), and endurance (**C**) after explosive resistance training in older adults. Graphs display the average relative (%) change from baseline across the five exercises used (mean ± standard deviation). G80 = high-intensity (80% 1RM) group; G50 = medium-intensity (50% 1RM) group; G20 = low-intensity (20% 1RM) group; CON = control group. There were highly significant time effects ($p < .0001$) and group-by-time interactions ($p < .0001$) for average change in peak power, strength, and endurance. Analysis of covariance (ANCOVA) models for peak power and strength were adjusted for baseline value and fat-free mass. ANCOVA model for endurance was adjusted for baseline value and habitual physical activity. Fisher's protected-least-significant-difference post hoc comparisons revealed: *significantly greater than CON ($p < .004$); †significantly greater than G20 ($p < .05$); ‡significantly greater than G50 ($p < .05$).

(30%–40% 1RM) (33,35,40), moderate (50%–60% 1RM) (7,41,42), heavy (70%–90% 1RM) (29,30,35), and even maximal loads (33,43). It is possible that group differences were minimized by the weekly strength testing used to precisely define the training stimulus in our study. This is, to our knowledge, the first published dose-response study of power training intensity in older adults.

Optimal intensity during explosive resistance training using isotonic equipment has been investigated twice in small cohorts of young men with no clear dose-response relationships emerging (33,35). Moss and colleagues (35) found significant and similar improvements in peak power of the elbow flexors following unilateral training at intensities of 15%, 35%, or 90% 1RM. However, improvements in the trained arm of the lightest group were no different than their contralateral nontrained control arm. Kaneko and colleagues (33) found that, although an intensity of 30% of maximal isometric strength (MIS) produced significantly greater improvements in peak power compared to 60% MIS or 0% MIS ($p < .01$), training at 100% MIS (isometric) was similarly effective. In the present study, absolute changes in total peak power using moderate loads (50% 1RM) were similar to those using heavy loads (80% 1RM), but greater than those using light loads (20% 1RM). Therefore, little or no loading (≤20% 1RM) may be suboptimal for improving absolute peak power compared to higher intensities.

To our knowledge, there have been only four published studies designed to improve muscle power in older adults through the exclusive use of explosive isotonic movements (25,26,29,30). Fielding and colleagues (30) compared explosive resistance training to traditional resistance training at the same intensity (70% 1RM) in 30 older women (73 ± 1 years) with self-reported disability over 16 weeks. Leg press and leg extension peak power improved by 97% and 33%, respectively, in the explosive resistance-training group. The improvements in peak power of 9%–14% in the leg press and 14%–18% in the leg extension (Table 3) in the present study are low by comparison; however, Fielding's study population was selected for self-reported functional impairment. In addition, the duration and volume of training was greater in Fielding's study, totalling 144 sets per exercise (three sets; 3 days/week) over 16 weeks compared to 50 sets (two to three sets; 2 days/week) over an average of 10 weeks in the present study.

A randomized controlled trial comparing explosive to traditional resistance training was recently conducted by Miszko and colleagues (26) in 39 older adults with below-average leg extensor power. At the end of the 16-week intervention, peak power was not significantly different between the strength (80% 1RM) and power (40% 1RM) training groups or compared to nontraining controls. By contrast, in the present study, explosive resistance training at 20%, 50%, or 80% made significant improvements in peak power compared to controls in each exercise. However, Miszko and colleagues (26) assessed peak power using the 30-second Wingate Anaerobic cycle Test (model 814E; Monarch, Varberg, Sweden); thus, the skill and metabolic challenge of the test may have confounded results.

Earles and colleagues (29) compared 12 weeks of explosive resistance training incorporating machine (leg press, 50%–70% 1RM) and free-weight exercise (step ups, chair raises, hip flexion, and plantar flexion using weighted vests and ankle weights) to a self-paced walking program in

43 highly functioning older adults. Improvements in leg press peak power (22%, $p = .004$) with power training were greater compared to walking, and closer to those found in the present study.

Bean and colleagues (25) compared 12 weeks of power training, exclusively performing high-velocity weighted stair climbing (average climbing speed of 90.9% of maximum power) compared to a walking program in 45 mobility-limited older adults. A 17% improvement in leg press peak power in the power-training group was reported compared to the walking (control) group ($p = .013$). However, no significant improvement occurred in leg extension peak power after stair climbing. In addition, no significant group difference in stair-climbing power was found (12% power training vs 6% walking; $p = .129$), perhaps due to insufficient sample size.

All previous power-training studies in older adults have been relatively small in size and have reported changes in lower body power only. Our study presents the largest cohort of older adults to undergo explosive resistance training. It is also the first to investigate the efficacy of low-intensity explosive resistance training at 20% 1RM in older adults, and to report the efficacy of explosive resistance training for improving peak power of upper body musculature in older adults.

Muscle Strength

As we hypothesized, a dose-response relationship was found between training intensity and improvements in strength in this study. This finding supports those of previous dose-response studies in explosive (33,35) and traditional (44) resistance training for dynamic (35,44) and isometric strength (33).

The 15%–27% improvements in strength experienced by the high (80% 1RM) intensity group in the present study are consistent with some (29) and greater than other (25,26) power-training studies of similar duration in older adults. For example, Earles and colleagues (29) reported a 22% increase in leg press strength, whereas Bean and colleagues (25) found no significant increase after 12 weeks of stair-climbing power training. In addition, changes in strength were no different between power-training and walking control groups in either study, despite the presence of group differences for peak power (25,29). Thus, machine-based high-intensity explosive resistance training may be a better strategy than high intensity stair-climbing based programs for simultaneously improving peak power and strength in older adults.

Surprisingly, even the lightest (20% 1RM) training group made modest strength improvements in each exercise (9%–16%) compared to nontraining controls in our study. Conversely, Moss and colleagues (35) found the increase in unilateral elbow flexor strength with light-intensity training (15% 1RM) was no different between trained and nontrained arms. In addition, Kaneko and colleagues (33) found no significant increase in isometric strength with unloaded training. However, the weekly 1RM assessments conducted in the present study may have constituted one high-intensity set and contributed to the increase in strength in the lighter training groups. One weekly high-intensity set has shown to improve multiple joint angle isometric cervical extension strength by approximately 10% after 12 weeks in younger adults (45). Therefore, using heavy loads during explosive resistance training elicits the greatest strength improvements in older adults, with little or no loading yielding suboptimal results.

Muscle Endurance

We found a dose-response relationship between training intensity and local muscular endurance. This relationship was also found in a recent 10-week study by Seynnes and colleagues (44). They investigated the effect of training intensity (80% vs 40% 1RM) during traditional resistance training in 22 institutionalized older adults (81.5 ± 1.4 years). Both low- and high-intensity groups significantly improved in comparison to ''nonloaded training'' controls ($p < .0001$), with improvement in the high intensity group (285 ± 75%) significantly better than in the low intensity group (118 ± 31%, $p = .008$). Similarly, Pu and colleagues (46) found an increase of 299 ± 66% in local muscular endurance after 10 weeks of traditional high-intensity resistance training in comparison to matched placebo controls (1 ± 3%, $p = .001$) in 16 older women with congestive heart failure. The use of high-intensity resistance training to improve local muscular endurance is contrary to current resistance training recommendations for older adults, which suggest the use of low to moderate loads based on studies in younger adults (32). This is the first study to demonstrate optimal development of local muscular endurance using heavy loads during explosive resistance training in older adults.

Feasibility and Safety

Explosive resistance training with light, medium, and heavy loads was well tolerated in our cohort of healthy older adults, as in previous power-training studies of similar duration (25,29). The rate of adverse events for strength testing and power training was very low (0.34% and 0.25%, respectively). Traditional high-intensity resistance training has been safely conducted in older adults (20,21,26,30,44,46–48). High-intensity explosive resistance training appears to present no greater risk of complications (25,29,30).

Limitations

There were several limitations to this study. As discussed, the weekly strength tests may have influenced primary outcomes, especially strength and power in the moderate and light training groups. The duration of the study was relatively short. A longer intervention or greater volume of exercise may reveal differences among groups for peak power and body composition. Nonblinded final testing could have biased the results.

Conclusions

Peak power, strength, and local muscular endurance are important physical attributes to maintain in later life for the retention of functional ability and independence. Exercise prescription should therefore aim to enhance all three muscular qualities in the simplest, most time-efficient manner. Our findings demonstrate that explosive resistance training at light, moderate, and high intensities gives similar relative improvements in peak power, whereas high-intensity training provides the best improvements in strength and local muscular endurance. Therefore, high-intensity explosive resistance training presents the best strategy for simultaneous improvements in whole-body peak power, strength, and local muscular endurance in healthy older adults. Generalizability of these findings to other cohorts of older adults at risk for muscle dysfunction and disability is warranted.

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