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ORIGINAL RESEARCH

Traditional Versus Functional Strength Training: Effects on Muscle Strength and Power in the Elderly

Hilde Lohne-Seiler, Monica K. Torstveit, and Sigmund A. Anderssen

The aim was to determine whether strength training with machines vs. functional strength training at 80% of one-repetition maximum improves muscle strength and power among the elderly. Sixty-three subjects (69.9 ± 4.1 yr) were randomized to a high-power strength group (HPSG), a functional strength group (FSG), or a nonrandomized control group (CG). Data were collected using a force platform and linear encoder. The training dose was 2 times/wk, 3 sets × 8 reps, for 11 wk. There were no differences in effect between HPSG and FSG concerning sit-to-stand power, box-lift power, and bench-press maximum force. Leg-press maximum force improved in HPSG (19.8%) and FSG (19.7%) compared with CG (4.3%; $p = .026$). Bench-press power improved in HPSG (25.1%) compared with FSG (0.5%, $p = .02$) and CG (2%, $p = .04$). Except for bench-press power there were no differences in the effect of the training interventions on functional power and maximal body strength.

Keywords: weight training, high velocity, force, seniors

Human aging leads to a progressive loss of muscle strength, mostly because of atrophy of muscle mass and loss of muscle fibers (Lexell, 1997; Lexell, Taylor, & Sjöström, 1988). Age-related reductions in muscle mass are primarily a consequence of losses of alpha motor neurons in the spinal cord and secondary denervation of their muscle fibers (Lexell, 1993, 1997). A reduction of muscle fibers is associated with motor-unit loss, mainly after 60 years of age (Lexell, 1993). Fast-twitch motor units are the most affected. In addition, qualitative changes in muscle cross-sectional area are reported with increasing age, which results in a dramatic loss in the ability to produce force rapidly (De Vito et al., 1998; Izquierdo, Aguado, Gonzalez, Lopez, & Häkkinen, 1999). Muscle power, defined as the product of force and velocity (Power = force × velocity), therefore declines more than muscle strength (Skelton, Greig, Davies, & Young, 1994). Muscle power has been shown to be positively associated with the ability to perform activities of daily living and may be a stronger predictor of functional dependency than muscle strength is (Bean et al., 2003; Foldvari et al., 2000).

Lohne-Seiler and Torstveit are with the Faculty of Health and Sport Sciences, University of Agder, Kristiansand, Norway. Anderssen is with the Dept. of Sport Medicine, Norwegian School of Sport Sciences, Oslo, Norway.

A significant correlation between leg-extensor power and performance measures, such as the ability to rise from a chair, climb stairs, and walk quickly, has been shown (Bassey et al., 1992; Foldvari et al., 2000). Muscle power is also related to dynamic balance (Bean et al., 2002) and postural sway (Izquierdo et al., 1999) and may be a stronger predictor of fall risk than muscle strength is (Skelton, Kennedy, & Rutherford, 2002). Furthermore, increased muscle power may lead to improvements in functional capacity, fall prevention, dependency, and disability later in life (de Vos, Singh, Ross, Stavrinos, Orr, & Fiatarone Singh, 2005).

It is not clear what form of strength training is most beneficial for the elderly. There are different views concerning strength-training protocols where the goal is to maintain or attain an adequate level of physical function, to perform activities of daily living successfully and independently. High-intensity (Fiatarone et al., 1990), low-intensity (Skelton, Young, Grieg, & Malbut, 1995), high-velocity in combination with high-intensity (Henwood & Taaffe, 2005; Macaluso, Young, Gibb, Rowe, & De Vito, 2003), high-velocity versus traditional low-velocity resistance training at the same training intensity (Fielding et al., 2002), high-velocity versus traditional low-velocity resistance training at different training intensities (Miszko et al., 2003), and functional task-oriented strength training (de Vreede, Samson, van Meeteren, Duursma, & Verhaar, 2005; Helbostad, Sletvold, & Moe-Nilssen, 2004) have all been investigated. A traditional protocol for the elderly focuses on high-intensity and low-velocity strength training (Fiatarone et al., 1990). High-intensity strength training, equivalent to ~80% of one-repetition maximum (1RM), is effective for increasing muscle size and strength (Fiatarone et al., 1990; Frontera, Meredith, O'Reilly, Knuttgen, & Evans, 1988; Taaffe, Duret, Wheeler, & Marcus, 1999). However, this training regimen, because of the slow speed of muscle contraction, may lead to lack of muscle power. Using heavy loads (80% of 1RM) during explosive resistance training may be the most effective strategy to achieve simultaneous improvements in muscle strength and power in older adults (de Vos et al., 2005). Power-training studies in the elderly have mostly focused on lower body power (de Vos et al., 2005; Fielding et al., 2002; Henwood & Taaffe, 2005; Macaluso et al., 2003). However, if the goal is to elicit improvements in functional movement capacity among older adults, it is also necessary to integrate the upper body in the training program and improve peak power in the upper body musculature. Furthermore, exercise strategies for the elderly should be designed to increase muscle power in functional movements. However, little is known about the functional adaptive responses of elderly subjects to power training (Evans, 2000).

The aim of the current study was to test the hypothesis that functional strength training performed at 80% of 1RM at a maximal intended concentric velocity would improve strength and power in functional strength tasks among elderly subjects more than traditional strength training at the same intensity and velocity.

Methods

Study Design and Participants

The subjects were recruited through advertisement in the local newspaper. A total of 110 people showed their interest after the first information meeting. Because of limited capacity, 70 volunteers (35 men, 35 women) were randomly stratified by sex out of the total number of 110. The subjects were randomized into two intervention groups: a high-power strength group (HPSG, $n = 25$) and a functional strength group (FSG, $n = 30$). Based on the capacity of the fitness center and the number of instructors available, the size of the HPSG was necessarily smaller than FSG. Finally, 15 subjects volunteered to be nontraining controls (CG) and were therefore a nonrandomized group (Figure 1).

Before participation, all subjects reported their health history and physical activity level through a questionnaire. In addition, they received medical clearance from their medical doctor, either in written or oral form. Inclusion criteria were being 65 years or older, physically active less than 30 min/day at moderate intensity, and healthy enough to participate. Exclusion criteria were being physically active more than 30 min/day at moderate intensity, participating in strength training, or involved in other studies interfering with the current study or having cognitive impairment, acute or terminal illness, or severe cardiovascular, respiratory, musculoskeletal, or neurological diseases disturbing voluntary movement. During the study period, the participants were encouraged to maintain their normal activity and dietary patterns.

The study was approved by the Regional Committee for Medical Research Ethics in Norway and the Data Inspectorate, and all subjects provided informed consent before the study.

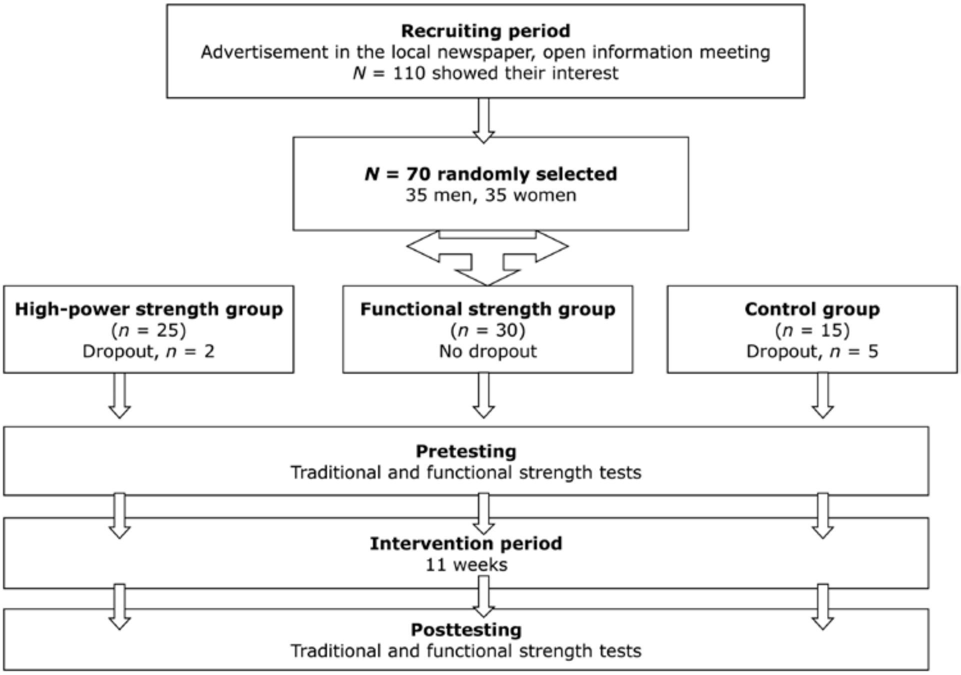

Figure 1 — A flowchart showing the study design.

Measures

On the first test day, participants completed a 20- to 30-min warm-up on a cycle ergometer (Monark, 818 E, Ergomed) before undergoing the traditional strength tests (leg-press, Smith-machine bench-press, and isometric dead-lift tests). On the second test day, approximately 1 week after the first test day, the participants completed a 20- to 30-min warm-up including fast walking and stair climbing before the functional strength tests (sit-to-stand power and box-lift power tests). This warm-up procedure was chosen because of the specificity of the functional movements. In the traditional strength tests, the muscle recruitment was as isolated as possible, in contrast to the functional strength tests where the muscle recruitment was as integrated as possible.

Leg-Press Tests. 1RM leg-press force and 80% of 1RM leg-press power were determined using a linear encoder and load cell connected to an integrated data-analysis program (Muscle Laboratory, Ergotest Technology AS, Norway). The subjects were encouraged to exert maximal force during the bilateral 1RM testing, after the same test procedure as described in Taaffe, Pruitt, Pyka, Guido, and Marcus (1996). To measure 80% of 1RM leg-press power, the subjects were asked to complete the concentric phase of the movement as rapidly as possible and then return through the eccentric phase at a slow and controlled pace over 2–3 s. The average of the two best attempts of five was recorded as the result. The same load lifted at 80% of 1RM at preintervention testing was used on the postintervention testing to reveal possible power changes for a given load.

Bench-Press Tests on the Smith Machine. 1RM bench-press force and 80% of 1RM bench-press power were determined using a linear encoder and load cell connected to the same integrated data-analysis program described earlier. Similar test procedures were followed as during the leg-press tests.

Isometric Dead-Lift Test. 1RM isometric dead-lift force was determined using a tension load cell connected to the integrated data-analysis program. The subjects were encouraged to exert maximal force during the 1RM testing. The better of two attempts was recorded. A total of 10% for women and 15% for men of the "average" maximum loads were calculated and then used during the box-lift test.

Sit-to-Stand Power Test. The sit-to stand power test, which is a test of lower extremity muscle power, was performed on a force platform (Figure 2[a]) connected to the integrated data-analysis program. The test is based on a validity and reliability study of the 30-s chair stand by Jones, Rikli, and Beam (1999; Lohne-Seiler, Anderssen, Blazevich, & Torstveit, 2012). After a given signal the subjects were encouraged to work as fast as possible and exert maximal power (a combination of fast speed and explosive work) while standing from a chair without handrails (height 46.0 cm, depth 44.5 cm). The average of the two best trials of five was recorded as the result. Five trials were necessary to ensure that the best sit-to-stand power result was achieved.

Box-Lift Power Test. The box-lift power test, which is a test of total-body lifting power, was performed using a linear encoder and load cell (Figure 2[b]) connected to the integrated data-analysis program. The test is based on a validity and reliability study of a version of the progressive isoinertial lifting test (Mayer et al., 1988)

(a) (b)

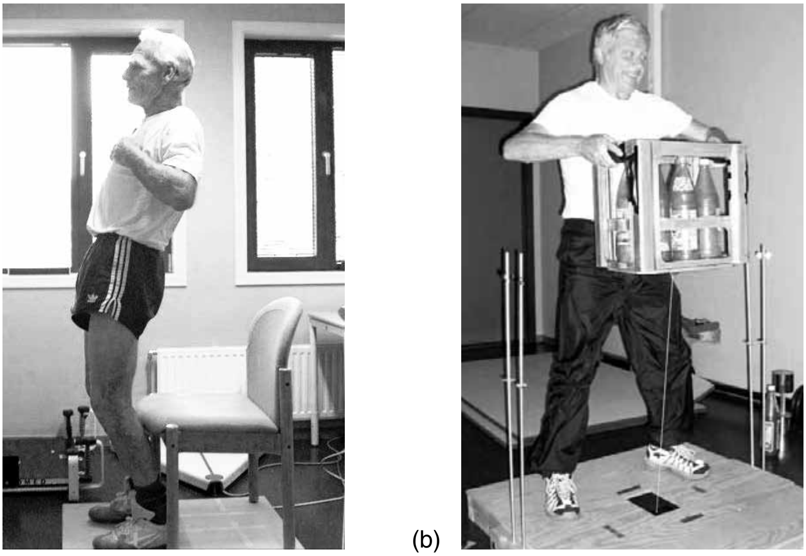

Figure 2 — Photos showing (a) sit-to-stand power test performed on a force platform and (b) box-lift power test performed using linear encoder and load-cell devices.

performed by Lohne-Seiler et al. (2012). During the box-lift test, 10% for women and 15% for men of the "average" maximum load achieved during the isometric dead-lift test were used. The subjects were encouraged to work as fast as possible and exert maximal power (a combination of fast speed and explosive work) during the box lifting. The average of the two best trials of five was recorded as the result. Five trials were necessary to ensure that the best box-lift power result was achieved.

Anthropometric Data. Body height and mass were measured using a measuring tape and body-mass monitor (Seca opima) twice per subject (wearing a T-shirt, shorts, and no shoes) ahead of the traditional and functional strength and power testing. The results are given as a mean of two measurements.

Exercise Intervention

The two intervention groups exercised twice a week for 11 weeks, with at least 48 hr between the two training sessions. The exercise program in the two intervention groups consisted of a 10-min warm-up including instructed aerobic and stretching exercises, followed by 50 min of instructed strength training using machines (HPSG) or functional strength training (FSG). Finally, a 10-min cooldown consisting of lower back, abdominal, and stretching exercises was completed under supervision in both the intervention groups.

HPSG subjects completed the following strength-training exercises in each training session: seated row, lat pull-down, shoulder press, leg press, and multipower

Figure 3 — Photos showing the machine-based strength-training exercises.

bench press on a Smith machine (Figure 3). The exercises were performed on TechnoGym equipment (Silver Line/Selection, Italy).

FSG subjects completed the following functionally based exercises in each training session: stair climbing using a backpack filled with training weights as the external load, box lifting using 2.25-kg bottles filled with sand as the external load, shoulder press and one-arm flies using dumbbells as the external load, and "rubber band rowing" using three different-resistance rubber bands as the external load. In addition, the participants in the FSG worked in an obstacle course consisting of sit-to-stand from a chair, hurdles, balance, and slalom challenges (Figure 4). They were asked to complete the obstacle course as correctly and quickly as possible.

All participants worked in pairs and were supervised by an instructor whose responsibility was to maintain set protocols and to establish a standard of security and motivation. Five instructors were engaged throughout the 11-week intervention, and each was responsible for the same exercises in the training period. The focus in the first 2 weeks (equivalent to four training sessions) of the intervention period was for the subjects to learn how to do the exercises, establish good training routines for the couples who worked together, get used to the training environment, and gain muscle conditioning.

In our study, the same training protocol was used as described in Jozsi, Campell, Joseph, Davey, and Evans (1999) and Henwood and Taaffe (2005). The first four training sessions had the following training procedure: For each exercise

Figure 4 — Photos showing a selected sample of the functionally based exercises.

the participants completed three sets of six to eight repetitions at 60% of 1RM (maximal weight an individual can lift one time) in the first set and 70% of 1RM in the second and third sets. Concentric and eccentric movements were performed in 2–3 s each. For the rest of the intervention period (equivalent to 18 training sessions) the training aimed specifically at increasing muscle power by using rapid concentric movements and increasing resistance intensities. Three sets of eight repetitions were performed at 60% of 1RM in the first set and 80% of 1RM in the second and third sets. The participants were instructed to perform the concentric phase of the movement as rapidly as possible, then return through the eccentric phase at a slow and controlled pace of 2–3 s. In the third set of exercises on the second training day each week, the subjects were asked to work past the eighth repetition until failure. If they managed to do 10 repetitions, the 1RM was increased by 5%. If they managed to do 12 repetitions, the 1RM was increased by 10%. The 1RM training percentages were then recalculated accordingly.

Subject participation was recorded at every training session, and those whose adherence was less than 84% were excluded from the study. This allowed them to be absent three times during the 21-session intervention period.

Data Analysis

All analyses were conducted using SPSS statistical software (version 13.0, SPSS Inc., Chicago, IL). One-way ANOVA with Bonferroni's post hoc test was used to analyze differences between groups at baseline. Within-group comparisons were made using Student's paired-sample *t* tests. Differences in the change in performance from pre- to postintervention testing between the three groups (HPSG, FSG, and CG) were analyzed by using one-way ANOVA with Bonferroni's post hoc test (three-group comparison). All the tests were two-tailed, and a *p* level of .05 was chosen for statistical significance. Results are given as $M \pm SD$. A power calculation was conducted in advance of the current study based on the work by Henwood and Taaffe (2005), looking at the changes in functional muscle strength. The analysis was based on an effect size of 1.0, where the size of the change in functional muscle strength was 10% and the standard deviation of the mean change was 10%. The power analysis gave a statistical power of 81% and alpha error level or confidence level of 5%, giving a sample size in each intervention group of 20 subjects and a sample size in the control group of 15 subjects.

Results

Seven subjects dropped out of the study, 2 from the HPSG for medical reasons and 5 subjects from the CG—4 for medical reasons and 1 due to a failure to complete the required number of testing sessions. The average attendance rate was 18 of 21 sessions in both intervention groups during the 11-week intervention period.

The mean age of the total sample ($N = 63$) was 69.9 ± 4.1 years (range 65–87). All the participants in this study lived at home, with no help or assistance from the health care system. They all reported a physical activity level less than 30 min/day of moderate-intensity activity. None of the subjects had any previous experience in weight lifting or strength training. Common activities among the elderly were walking/strolling, swimming, gardening, and household activities. No significant differences in the subject characteristics were found between the three groups at baseline (Table 1).

Functional Strength Tests

No significant differences were found between the groups at baseline for the functional strength tests (Table 2).

Table 1 Baseline Characteristics in the High-Power Strength Group (HPSG), the Functional Strength Group (FSG), and the Control Group (CG), *M* (*SD*)

	HPSG, *n* = 23	FSG, *n* = 30	CG, *n* = 10	*p*
Age, years	69.4 (4.0)	70.4 (4.3)	69.3 (4.2)	.7
Height, cm	172.1 (8.8)	172.6 (9.8)	174.3 (10.0)	.8
Mass, kg	75.6 (14.8)	79.2 (11.0)	79.3 (18.0)	.6
Body-mass index, kg/m^2	25.4 (3.7)	26.4 (2.9)	25.9 (4.3)	.6

Table 2 Pre- and Postintervention Test Results in Functional Muscle-Strength Tests in the High-Power Strength Group (HPSG), the Functional Strength Group (FSG), and the Control Group (CG), *M* (*SD*)

	HPSG			FSG			CG		
	Pre	Post	*n*	Pre	Post	*n*	Pre	Post	*n*
Sit-to-stand power test, W	814.1 (305.4)	909.5 (364.5)	23	841.4 (240.7)	909.0 (243.4)*	27	708.0 (336.7)	648.8 (240.2)	9
Box-lift power test, W	222.3 (151.7)	255.6 (167.3)*	23	260.0 (113.6)	282.9 (121.0)*	27	266.7 (192.1)	272.3 (198.8)	9

*Significant changes from pre- to postintervention were found (within-group comparison), $p \leq .05$.

Sit-to-Stand Power. Significant improvements from pre- to postintervention in the sit-to-stand power test were only found in FSG, $t = -3.168$, $df(26)$, $p = .004$ (Table 2; 67.6 ± 110.8 W, 9.7%), although this change was not significantly different, $F = 2.388$, $df(2, 56)$, $p = .101$, from HPSG (95.4 ± 247.0 W, 14.5%) or CG (–59.2 ± 155.8 W, –4.1%). The effect size was $\eta^2 = .50$.

Box-Lift Power. Both HPSG and FSG significantly improved their box-lift power, $t = -6.404$, $df(22)$, $p = .000$, and $t = -2.999$, $df(26)$, $p = .006$, respectively (Table 2; 33.3 ± 24.9 W, 19.2%, and 23.0 ± 39.8 W, 9.7%, respectively), although no differences between the groups were found, $F = 2.074$, $df(2, 56)$, $p = .135$, change in CG = 5.5 ± 41.4 W (3.3%). The effect size was $\eta^2 = .50$.

Traditional Strength Tests

No significant differences were found between the groups at baseline for the traditional strength tests (Table 3).

Leg-Press Force (1RM). Both HPSG and FSG significantly improved their leg-press maximum force, $t = -4.240$, $df(22)$, $p = .000$, and $t = -5.096$, $df(27)$, $p = .000$, respectively (Table 3; 203.4 ± 191.7 N, 19.8%, and 196.8 ± 200.7 N, 19.7%, respectively). Average force output during the leg-press maximum-force test significantly increased, $F = 3.978$, $df(2, 44)$, $p = .026$, from pre- to postintervention in both the intervention groups compared with CG (Table 3; change in CG = 14.2 ± 123.7 N, 4.3%, $p \leq .05$). The effect size was $\eta^2 = .50$. The subjects in HPSG and FSG managed to lift 24.8 ± 27.7 kg and 23.2 ± 24.4 kg, respectively, more at postintervention than CG (2.0 ±11.4 kg).

Leg-Press Power (80% of 1RM). CG significantly improved leg-press power from pre- to postintervention, $t = -2.386$, $df(9)$, $p = .041$ (Table 3; 39.4 ± 52.3 W, 16.6%), although this change was not different, $F = 1.792$, $df(2, 55)$, $p = .176$, from HPSG (0.04 ± 40.1 W, 0.3%) or FSG (4.1 ± 68.3 W, 2.9%). The effect size was $\eta^2 = .50$.

Bench-Press Force (1RM). Both HPSG and FSG significantly improved their bench-press maximum force, $t = -4.502$, $df(22)$, $p = .000$, and $t = -4.024$, $df(27)$, $p = .000$, respectively (Table 3; 51.0 ± 52.0 N, 15.2%, and 33.5 ± 46.9 N, 12.9%, respectively), although there were no differences in the changes among the groups, $F = 0.698$, $df(2, 47)$, $p = .502$; change in CG = 28.5 ± 59.9 N (14.7%). The effect size was $\eta^2 = .50$. The subjects in the HPSG and the FSG managed to lift 6.8 ± 5.6 kg and 4.1 ± 5.4 kg, respectively, more at postintervention than CG (3.0 ± 6.2 kg).

Bench-Press Power (80% of 1RM). HPSG significantly improved bench-press power from pre- to postintervention, $t = -3.324$, $df(21)$, $p = .003$ (Table 3; 27.6 ± 39.0 W, 25.1%). Otherwise, no significant changes were detected (Table 3). Average power output in the bench-press power test significantly increased, $F = 4.684$, $df(2, 54)$, $p = .013$, in HPSG (27.6 ± 39.0 W, 25.1%) compared with both FSG (–1.2 ± 33.5 W, 0.5%, $p = .02$) and CG (–0.4 ± 23.4 W, 2.0%, $p = .04$). The effect size was $\eta^2 = .50$.

Table 3 Pre- and Postintervention Test Results in Traditional Muscle-Strength Tests in the High-Power Strength Group (HPSG), the Functional Strength Group (FSG), and the Control Group (CG), *M* (*SD*)

	HPSG			FSG			CG		
	Pre	Post	*n*	Pre	Post	*n*	Pre	Post	*n*
Leg-press force test 1RM, N	1,117.6 (459.9)	1,359.2 (664.7)[a,b]	23	1,195.3 (370.5)	1,430.9 (524.8)[a,c]	28	1,142.3 (502.6)	1,156.5 (439.3)	10
Leg-press power test 80% of 1RM, W	314.6 (129.8)	314.6 (133.8)	21	338.9 (122.3)	343.0 (128.6)	27	282.9 (122.6)	322.3 (132.5)[a]	10
Bench-press force test 1RM, N	343.2 (131.2)	402.4 (166.6)[a]	23	353.9 (108.2)	393.8 (113.2)[a]	28	377.3 (188.5)	405.8 (168.6)	10
Bench-press power test 80% of 1RM, W	139.6 (71.4)	167.2 (86.5)[a,d]	22	141.7 (47.7)	140.5 (48.8)	25	143.8 (81.0)	143.4 (80.4)	10

Note. 1RM = one-repetition maximum.

[a]Significant changes from pre- to postintervention (within-group comparison), $p \leq .05$. [b]HPSG compared with CG, $p = .05$. [c]FSG compared with CG, $p = .04$. [d]HPSG compared with FSG, $p = .02$, and CG, $p = .04$.

Discussion

A main finding of the current study was that there was no difference in the effect on functional power and maximal body strength between the two training regimens, machine-based strength training versus functional strength training. However, a significant difference in effect was seen in traditional upper body power between the two intervention groups and the control group. Thus, higher speed strength training seems to be effective for the development of upper body strength and power in elderly subjects.

The intention of this study was to examine the difference in effect between strength training with machines and functional strength training, where both training regimens included work at a heavy load with maximal intended concentric velocity. This is different from other studies (Helbostad et al., 2004; Skelton et al., 1995) where the functional training regimes were completed at lower intensity and slower movement speeds. Few studies have compared these two training regimens, although one compared the effect of traditional resistance training versus functional strength training (de Vreede et al., 2005), and other studies have evaluated the effect of strength-training regimens at different movement speeds (Henwood, Riek, & Taaffe, 2008; Henwood & Taaffe, 2006).

Muscle Power Measured Functionally

Only FSG significantly improved in the sit-to-stand power test from pre- to postintervention. Similar results have previously been reported by Helbostad et al. (2004), who showed an effect of functional strength training on chair-stand performance, measured as the time an older adult takes to rise from a chair as fast as possible. No significant increase was seen in the current study in HPSG and FSG compared with CG in functional lower body power over the 11-week intervention period. Our result is not consistent with those of Henwood & Taaffe (2005, 2006), who found a significant improvement in chair-rise ability after a high-velocity resistance-training program. Their study had a low training specificity, only an 8-week intervention period, and a smaller number of participants in the training group ($n = 15$), so their results might be connected to the use of a combination of high-intensity and high-velocity movements. At least for the lower body musculature, it is possible that the use of separate high-intensity and high-speed sessions might be more effective than consistently using a single-session design where the concentric phase is performed as rapidly as possible. This hypothesis should be tested in future research.

In the box-lift power test both HPSG and FSG significantly improved from pre- to postintervention. These findings differ from those of Skelton et al. (1995), who found no change in bag-lifting performance after functional strength training. de Vreede et al. (2005) demonstrated that functional strength training had a significantly greater influence on activities of daily living than traditional strength training in a group of elderly subjects. This result might be explained by a high training specificity in the functional group and, based on this, we probably should have prevented FSG from doing box lifting, as it was too specific to the pre- and postintervention test. In our study, we found no significant differences in functional lower and upper body power between HPSG and FSG.

The significant improvement in functional power in FSG might be explained by a high training specificity, where the training and testing tasks were identical.

Conversely, the lack of functional body-power improvements in HPSG is probably due to a low training specificity. This is in agreement with Henwood and Taaffe (2005), as mentioned earlier, who found that the proportional change in functional strength was less than the change in "traditional" strength after higher velocity machine-based strength training.

The relative increase in functional-test performance in our study was greater in HPSG than in FSG, which might be explained by a better control of the speed of contraction (movement) and the greater training load used by HPSG than by FSG. Our subjects in both intervention groups were reminded on a regular basis to work at a high speed in the concentric phase, but slow and controlled (2–3 s) in the eccentric phase, although movement speed was not specifically measured. To control for the speed of contraction performed by the intervention groups, using timers or metronomes might be a solution. This would probably be helpful for researchers or practitioners interested in developing power-training protocols for their elderly subjects or clients.

Since we could not detect any difference between the two exercise groups, we combined the subjects and compared them with CG to increase statistical power. A significant improvement in sit-to-stand power was found in the combined intervention group (80.3 ± 184.7 W, equivalent to 11.9%) compared with CG (–59.2 + 155.8 W, equivalent to –4.1%; $p = .03$). A significant improvement in leg-press maximum force was also found in the combined intervention group (199.5 ± 194.4 N, equivalent to 20.2%) compared with CG (14.2 ± 123.7 N, equivalent to 4.3%; $p = .001$). This result shows that strength training with high intensity and high velocity, per se, might appear to have a substantial effect on both lower body strength and functional performance in older individuals, which is in agreement with previous research (Bottaro, Machado, Nogueira, Scales, & Veloso, 2007; Henwood et al., 2008; Henwood & Taaffe, 2005, 2006). Surprisingly, our result showed no significant increases in upper body performance when comparing the combined group with CG.

In our study, the functional abilities (sit-to-stand power and box-lift power) were measured objectively. Our findings are therefore difficult to compare with those of other studies where the power outcome in functional-tasks performance and abilities among the elderly were often measured indirectly in the field (de Vreede et al., 2005; Helbostad et al., 2004; Henwood & Taaffe, 2005; Miszko et al., 2003; Skelton et al., 1995). It is a methodological challenge to compare results based on two different test methods, field-based and objective-based tests. In addition, studies using functional-training regimens as interventions are hard to compare with our study, since those studies were not concerned with showing the intent to maintain the high intensity and the high velocity of the training but instead focused more on adapting the training exercises similar to activities of daily living (de Vreede et al., 2005; Helbostad et al., 2004).

According to de Vos et al. (2008), explosive resistance training in older adults results in their ability to produce higher peak power outputs with heavier loads without loss of movement velocity. The lack of significant improvements in functional power in our study may be connected to the estimated intensity and velocity. The high intensity was easier to control for in HPSG than in FSG. To ensure that the subjects in both intervention groups exerted maximal power during the tests, they were asked to work as fast as possible and at the same time think of the movement as being very explosive. It was important for the test leaders to ensure that the subjects fully understood the importance of this concept to exert maximal power. The velocity was more related to each individual's intention to work at high speeds. To ensure that this happened, both intervention groups were constantly reminded by the instructors to work fast in the concentric phase of the movement. The training intensity used in our study is in accordance with de Vos et al. (2005), who looked at the optimal load for increasing muscle power during explosive resistance training in elderly participants and found that heavy loads equal to 80% of 1RM may be the most effective strategy to achieve improvements in muscle strength and power. The training specificity in FSG was high, and therefore we had an expectation to influence the subjects' functional strength abilities. The lack of significant improvement is probably related to the issues we have explained, including controlling for the correct speed of movement and the training intensity.

Muscle Strength and Power Measured Traditionally

Leg-press maximum force significantly improved in HPSG and FSG compared with CG, and a significant increase in traditional upper body strength was seen in both HPSG and FSG from pre- to postintervention. However, no significant differences in the magnitude of change were found in bench-press maximum force among the groups after 11 weeks of training. Studies evaluating the effects of high-power strength training using machines showed positive results in both upper and lower maximal body strength (Bottaro et al., 2007; Henwood et al., 2008; Henwood & Taaffe, 2005, 2006). An important explanation for some of the strength gains in our study is the specificity of the training, which also might explain the outcomes of the studies cited. The participants in HPSG trained on the same machines on which they were tested. This might explain the outcome from the high-power strength training on the machines. An interesting issue in this regard is the effect we found on lower body maximum force (leg-press strength) after 11 weeks of functional strength training. The FSG subjects did not train using the test exercises, resulting in a low training specificity. The stair-climbing activity with external load on the back might have elicited enough of a strength adaptation to result in the increases in traditional lower body strength, even though the training exercise was unilateral while the testing was completed bilaterally.

Differences in the responses of men and women might partly explain the lack of significant differences in change among the groups in upper body strength. We reexamined the HPSG data, split by sex, and found a significant improvement in bench-press maximum force in men (23.2% compared to 1.5% in CG, $p < .02$) but not in women. Previous data (Janssen, Heymsfield, Wang, & Ross, 2000) have shown that men have more skeletal-muscle mass than women do and that these sex differences are greater in the upper body, which might be related to our results. Because the sample sizes are smaller when divided by sex, these data have not been presented in the Results section, but a more detailed between-sexes examination might be an important focus of future research.

No significant changes were found in leg-press power in HPSG and FSG after 11 weeks of training, and no change was noticed when the two training groups were combined—2.3 ± 57.1 W (1.8%), compared with 39.4 ± 52.3 W (16.6%) for CG. Henwood et al. (2008), on the other hand, demonstrated enhanced lower body muscle power after a period of high-velocity resistance training, which might be explained by their longer intervention period of 24 weeks. The small improvement in CG is difficult to explain but may indicate a possible learning effect in CG that might have been greater than in the intervention groups because they did not perform weekly training and therefore had no interference after learning the test. Similar results have been reported in another study (Henwood & Taaffe, 2005) that found small (nonsignificant) increases in average knee-extension power after 8 weeks of high-velocity resistance training. In upper body power, on the contrary, only HPSG significantly improved bench-press power from pre- to postintervention, with this increase being statistically greater than in FSG and CG. These results are probably due to the high-intensity and high-velocity movements that HPSG subjects completed during the 11-week intervention. Few studies (Bottaro et al., 2007) have demonstrated the effects of power training on upper body power. Muscle power, or the ability to produce force rapidly, has emerged as an important predictor of functioning in older men and women (Sayers, 2007). The conclusion of a review detailing the functional benefits of power training for the elderly was that standard resistance training is effective in increasing strength in older adults, but power training incorporating high-velocity contractions might be more optimal when the emphasis is on enhancing the performance of activities of daily living (Hazell, Kenno, & Jakobi, 2007). If it is possible to maintain high intensities and high velocities when using functional movements, like the FSG did in our study, this might lead to higher strength and power outcomes and increased functional benefits. Unfortunately, the results from the current study are not able to prove it.

Overall, strength training with machines produced a greater outcome in traditional strength and power tests than did functional strength training, despite the fact that both groups had the intention to work at both a high training intensity and a high training velocity.

Physiological Adaptations

The precise neurological adaptations resulting from high-intensity and high-velocity strength training, and in particular whether changes are greater at the spinal-cord level or the degree of firing rates within the motor units (Carroll, Riek, & Carson, 2001), are not completely known. It is possible to speculate that this specific strength training leads to an increase in the number and diameter of motor neurons in the ventral root in the spinal cord, and faster nerve impulses in both afferent and efferent nerve cells would arise, leading to improved neuromuscular adaptation. Overall, this would lead to increased motor responses. These physiological adaptations are not well documented in the literature (Reeves, Maganaris, & Narici, 2003). However, increased muscle cross-sectional area in elderly subjects as a result of high-intensity strength training *is* well documented (Harridge, Kryger, & Stensgaard, 1999; Patten & Kamen, 2000; Reeves et al., 2003), and it probably influenced the performance adaptations seen in the current study.

Strengths and Limitations of the Study

The strengths of the current study are randomized intervention groups, use of objective validated functional tests, and high training compliance of the participants. There are some limitations to the study that need to be addressed. One of them is the nonrandomized CG. There were, however, no differences between the three groups at baseline, indicating homogeneous groups based on age, height, weight, and body-mass index. Another limitation is the moderate dropout rate in CG. The fact that 5 of 15 controls dropped out of the study, 4 for medical reasons and 1 due to a failure to complete the required number of testing sessions, makes the sample size in the CG small. In an attempt to prevent dropouts in the CG, we could have established a social arena for the controls during the intervention period and invited them to be involved with an activity—a flexibility-training program—of the same duration and frequency as the intervention groups, but not related to the intervention, which would affect the outcome measures. Another issue in this regard is the significant improvement in leg-press power from pre- to postintervention in the CG. The low number of controls and a possible learning effect may explain this outcome, and as mentioned earlier similar results have been reported by Henwood et al. (2008), where the CG had a significant increase in average leg-curl power. Nonetheless, the fact that there were only 2 dropouts in HPSG (medical reasons) and none in FSG is a strength of the current study.

The lack of statistically significant findings may be related to the high variability (*SD*) of the changes. To minimize this variability, an even better control of the participants' training status, by measuring their physical fitness level, could have been carried out before inclusion. However, in the recruitment phase of the study the goal was to make sure the participants were quite homogeneous according to their activity level and health status, based on a questionnaire. In addition, all participants were community-dwelling people and were able to get to the training facilities and back home without any assistance. This effort was taken to ensure that the participants were as homogeneous as possible. Since no significant differences were found between the groups at baseline based on age, height, body mass, and body-mass index, it is likely that their training status was quite similar.

In addition, the participants could have been invited to the gym to practice in advance of the preintervention testing, to ensure that they were more familiar with the test and exercise environment. There is some consideration with conducting only one session of strength testing at baseline that could be addressed in future studies. When we started the intervention, we intended to complete two testing sessions for both the traditional and the functional strength tests, as part of the baseline measures, to reduce a possible learning effect. Unfortunately, based on a limited ability to use the laboratories for testing, we were not able to complete more than one testing session for each test at baseline. However, to ensure that all the participants felt comfortable with the different tests, they also got an extra attempt, meaning a practice run, before the testing started. Another possible explanation for the lack of statistical significance is the training volume and the duration of the intervention period. Maybe an 11-week intervention period is too short, and a training frequency of two sessions per week is too low. Both the duration and the frequency of training might be increased in future studies to provide a greater training stimulus. However, most previous studies have used twice-weekly training and an intervention period of 8–24 weeks (de Vos et al., 2008; Henwood et al., 2008; Henwood & Taaffe, 2005).

Studies in the area of power training designed for the elderly have mostly focused on lower body power (de Vos et al., 2005; Fielding et al., 2002; Henwood & Taaffe, 2005; Macaluso et al., 2003). To investigate the combination of high-intensity and high-velocity training and the effect on both traditional and functional muscle strength and power involving upper and lower extremities, as in our study, is novel. We found that there might be a practical value from high-power strength training using machines to power gains in activities of daily living, measured as box lifting and sit-to-stand. These are bilateral activities, similar to the way the participants trained on the machines, which may be part of the reason for the increases in performance. However, the training specificity was low. From this perspective, it is interesting to see that traditional power training might have an application to functional power. Further research should be undertaken to define the mechanisms underlying this adaptation and to develop test regimens measuring muscle power and strength in functional task-oriented activities in an objective way. A measurement of muscle hypertrophy would probably have increased the scientific impact of this study and might have explained the limited effect of high-power strength training on muscle strength and power.

Conclusion

The current study revealed no difference in the effects of strength training with machines and functional strength training on functional power and traditional maximal upper body strength. Both intervention groups significantly improved maximal strength measured in the leg press compared with the CG. A significant difference in effect was found in traditional upper body power between the two intervention groups and the control group. HPSG significantly improved bench-press power compared with both FSG and CG. Both intervention groups significantly increased functional upper body power and traditional maximal upper body strength from pre- to postintervention. Based on our results, there seems to be a transfer from high-power strength training to functional power gains in the elderly. Future studies should therefore investigate the effect of different power-training protocols to improve functional ability in the elderly and, in this way, determine the most effective power-training regimen.

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References

Bassey, E.J., Fiatarone, M.A., O'Neill, 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. PubMed

Bean, J.F., Kiely, D.K., Herman, S., Leveille, S.G., Mizer, K., Frontera, W.R., & Fielding, R.A. (2002). The relationship between leg power and physical performance in mobility-limited older people. *Journal of the American Geriatrics Society, 50*(3), 461–467. PubMed doi:10.1046/j.1532-5415.2002.50111.x

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 Medicine Sciences, 58*(8), 728–733. PubMed doi:10.1093/gerona/58.8.M728

Bottaro, M., Machado, S.N., Nogueira, W., Scales, R., & Veloso, J. (2007). Effect of high versus low-velocity resistance training on muscular fitness and functional performance in older men. *European Journal of Applied Physiology, 99*(3), 257–264. PubMed doi:10.1007/s00421-006-0343-1

Carroll, T.J., Riek, S., & Carson, R.G. (2001). Neural adaptations to resistance training: Implications for movement control. *Sports Medicine (Auckland, N.Z.), 31*(12), 829–840. PubMed doi:10.2165/00007256-200131120-00001

De Vito, G., Bernardi, M., Forte, R., Pulejo, C., Macaluso, A., & Figura, F. (1998). Determinants of maximal instantaneous muscle power in women aged 50–75 years. *European Journal of Applied Physiology and Occupational Physiology, 78*(1), 59–64. PubMed doi:10.1007/s004210050387

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. Series A, Biological Sciences and Medicine Sciences, 60*(5), 638–647. PubMed doi:10.1093/gerona/60.5.638

de Vos, N.J., Singh, N.A., Ross, D.A., Stavrinos, T.M., Orr, R., & Fiatarone Singh, M.A. (2008). Effect of power-training intensity on the contribution of force and velocity to peak power in older adults. *Journal of Aging and Physical Activity, 16*(4), 393–407. PubMed

de Vreede, P.L., Samson, M.M., van Meeteren, N.L., Duursma, S.A., & Verhaar, H.J. (2005). Functional-task exercises versus resistance strength exercise to improve daily function in older women: A randomized, controlled trail. *Journal of the American Geriatrics Society, 53*(1), 2–10. PubMed doi:10.1111/j.1532-5415.2005.53003.x

Evans, W.J. (2000). Exercise strategies should be designed to increase muscle power. *Journals of Gerontology. Series A, Biological Sciences and Medicine Sciences, 55*(6), 309–310. doi:10.1093/gerona/55.6.M309

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: Effects on skeletal muscle. *Journal of the American Medical Association, 263*(22), 3029–3034. PubMed doi:10.1001/jama.1990.03440220053029

Fielding, R.A., LeBrasseur, N.K., Cuoco, A., Bean, J., Mizer, K., & Fiatarone Singh, M.A. (2002). High-velocity resistance training increases skeletal muscle peak power in older women. *Journal of the American Geriatrics Society, 50*(4), 655–662. PubMed doi:10.1046/j.1532-5415.2002.50159.x

Foldvari, M., Clark, M., Laviolette, L.C., Bernstein, M.A., Kaliton, D., Castaneda, C., . . . Singh, M.A. (2000). Association of muscle power with functional status in community-dwelling elderly women. *Journals of Gerontology. Series A, Biological Sciences and Medicine Sciences, 55*(4), 192–199. doi:10.1093/gerona/55.4.M192

Frontera, W.R., Meredith, C.N., O'Reilly, K.P., Knuttgen, H.G., & Evans, W.J. (1988). Strength conditioning in older men: Skeletal muscle hypertrophy and improved function. *Journal of Applied Physiology, 64*(3), 1038–1044. PubMed

Harridge, S.D., Kryger, A., & Stensgaard, A. (1999). Knee extensor strength, activation, and size in very elderly people following strength training. *Muscle & Nerve, 22*(7), 831–839. PubMed doi:10.1002/(SICI)1097-4598(199907)22:7<831::AID-MUS4>3.0.CO;2-3

Hazell, T., Kenno, K., & Jakobi, J. (2007). Functional benefit of power training for older adults. *Journal of Aging and Physical Activity, 15*(3), 349–359. PubMed

Helbostad, J.L., Sletvold, O., & Moe-Nilssen, R. (2004). Effects of home exercises and group training on functional abilities in home-dwelling older persons with mobility and balance problems. A randomized study. *Aging Clinical and Experimental Research, 16*(2), 113–121. PubMed

Henwood, T.R., Riek, S., & Taaffe, D.R. (2008). Strength versus muscle power-specific resistance training in community-dwelling older adults. *Journals of Gerontology. Series A, Biological Sciences and Medicine Sciences, 63*(1), 83–91. PubMed doi:10.1093/gerona/63.1.83

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. PubMed doi:10.1159/000082195

Henwood, T.R., & Taaffe, D.R. (2006). Short-term resistance training and the older adult: The effect of varied programmes for the enhancement of muscle strength and functional performance. *Clinical Physiology and Functional Imaging, 26*(5), 305–313. PubMed doi:10.1111/j.1475-097X.2006.00695.x

Izquierdo, M., Aguado, X., Gonzalez, R., Lopez, J.L., & Häkkinen, K. (1999). Maximal and explosive force production capacity and balance performance in men of different ages. *European Journal of Applied Physiology and Occupational Physiology, 79*(3), 260–267. PubMed doi:10.1007/s004210050504

Janssen, I., Heymsfield, S.B., Wang, Z.M., & Ross, R. (2000). Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *Journal of Applied Physiology, 89*(1), 81–88. PubMed

Jones, C.J., Rikli, R.E., & Beam, W.C. (1999). A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Research Quarterly for Exercise and Sport, 70*(2), 113–119. PubMed

Jozsi, A.C., Campell, 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 Medicine Sciences, 54*(11), 591–596. doi:10.1093/gerona/54.11.M591

Lexell, J. (1993). Ageing and human muscle: Observations from Sweden. *Canadian Journal of Applied Physiology, 18*(1), 2–18. PubMed doi:10.1139/h93-002

Lexell, J. (1997). Evidence for nervous system degeneration with advancing age. *The Journal of Nutrition, 127*(5), 1011S–1013S. PubMed

Lexell, J., Taylor, C.C., & Sjöström, M. (1988). What is the cause of aging atrophy? Total number size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *Journal of the Neurological Sciences, 84*(2-3), 275–294. PubMed doi:10.1016/0022-510X(88)90132-3

Lohne-Seiler, H., Anderssen, S.A., Blazevich, A., & Torstveit, M.K. (2012). Reliability and validity of chair-stand and box-lift tests in elderly subjects. Manuscript submitted for publication.

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. PubMed

Mayer, T.G., Barnes, D., Kishino, N.D., Nichols, G., Gatchel, R.J., Mayer, H., & Mooney, V. (1988). Progressive isoinertial lifting evaluation I. A standardized protocol and normative database. *Spine (Philadelphia, PA, 1976), 13*(9), 993–997. PubMed doi:10.1097/00007632-198809000-00005

Miszko, T.A., Cress, M.E., Slade, J.M., Covey, C.J., Agrawal, S.K., & Doerr, C.E. (2003). Effects of strength and power training on physical function in community-dwelling older adults. *Journals of Gerontology. Series A, Biological Sciences and Medicine Sciences, 58*(2), 171–175. doi:10.1093/gerona/58.2.M171

Patten, C., & Kamen, G. (2000). Adaptations in motor unit discharge activity with force control training in young and older human adults. *European Journal of Applied Physiology, 83*(2-3), 128–143. PubMed doi:10.1007/s004210000271

Reeves, N.D., Maganaris, C.N., & Narici, M.V. (2003). Effects of strength training on human patella tendon mechanical properties of older individuals. *The Journal of Physiology, 548*(Pt. 3), 971–981. PubMed doi:10.1113/jphysiol.2002.035576

Sayers, S.P. (2007). High-speed power training: A novel approach to resistance training in older men and women. A brief review and pilot study. *Journal of Strength and Conditioning Research, 21*(2), 518–526. PubMed

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. PubMed doi:10.1093/ageing/23.5.371

Skelton, D.A., Kennedy, J., & Rutherford, O.M. (2002). Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. *Age and Ageing, 31*(2), 119–125. PubMed doi:10.1093/ageing/31.2.119

Skelton, D.A., Young, A., Grieg, C.A., & Malbut, K.E. (1995). Effects of resistance training on strength, power, and functional abilities of women aged 75 and older. *Journal of the American Geriatrics Society, 43*(10), 1081–1087. PubMed

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

Taaffe, D.R., Pruitt, L., Pyka, G., Guido, D., & Marcus, R. (1996). Comparative effects of high- and low-intensity resistance training on thigh muscle strength, fiber area, and tissue composition in elderly women. *Clinical Physiology (Oxford, England), 16*(4), 381–392. PubMed doi:10.1111/j.1475-097X.1996.tb00727.x