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Power training using pneumatic machines vs. plate-loaded machines to improve muscle power in older adults

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ABSTRACT

Objectives: Power training has been shown to be more effective than conventional resistance training for improving physical function in older adults; however, most trials have used pneumatic machines during training. Considering that the general public typically has access to plate-loaded machines, the effectiveness and safety of power training using plate-loaded machines compared to pneumatic machines is an important consideration. The purpose of this investigation was to compare the effects of high-velocity training using pneumatic machines (Pn) versus standard plate-loaded machines (PL).

Methods: Independently-living older adults, 60 years or older were randomized into two groups: pneumatic machine (Pn, n = 19) and plate-loaded machine (PL, n = 17). After 12 weeks of high-velocity training twice per week, groups were analyzed using an intention-to-treat approach. Primary outcomes were lower body power measured using a linear transducer and upper body power using medicine ball throw. Secondary outcomes included lower and upper body muscle muscle strength, the Physical Performance Battery (PPB), gallon jug test, the timed up-and-go test, and self-reported function using the Patient Reported Outcomes Measurement Information System (PROMIS) and an online video questionnaire. Outcome assessors were blinded to group membership.

Results: Lower body power significantly improved in both groups (Pn: 19%, PL: 31%), with no significant difference between the groups (Cohen's $d = 0.4$, 95% CI (-1.1, 0.3)). Upper body power significantly improved only in the PL group, but showed no significant difference between the groups (Pn: 3%, PL: 6%). For balance, there was a significant difference between the groups favoring the Pn group ($d = 0.7$, 95% CI (0.1, 1.4)); however, there were no statistically significant differences between groups for PPB, gallon jug transfer, muscle muscle strength, timed up-and-go or self-reported function. No serious adverse events were reported in either of the groups.

Conclusions: Pneumatic and plate-loaded machines were effective in improving lower body power and physical function in older adults. The results suggest that power training can be safely and effectively performed by older adults using either pneumatic or plate-loaded machines.

Aging, even in the absence of overt disease, leads to a gradual decline in muscle mass and muscle muscle strength (Frontera et al., 2008). This progressive decline can result in the loss of physical independence, increased fall probability, poor quality of life, increased health care costs and lowered life expectancy (Janssen, 2002; Lord et al., 1994). It has been estimated that 20–30% of community-dwelling older adults report poor mobility and impairments in instrumental (IADL) and basic (BADL) activities of daily living (Fried et al., 2004).

Over the past two decades, muscle power has gained prominence as an important determinant of physical function in the aging population (Reid and Fielding, 2012). During the aging process, muscle power declines at a faster rate than muscle strength and shows a stronger association with physical function than muscle strength or muscle mass (Bean et al., 2003; Skelton et al., 1994). Power-training, often called high-velocity resistance training, is characterized by a rapid concentric phase (muscle shortening) followed by a slower eccentric phase (muscle lengthening) using moderate to high loads. Multiple systematic reviews and meta-analyses have now shown that power training may be more

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beneficial for improving older persons' power and function than conventional resistance training (Byrne et al., 2016; Reid and Fielding, 2012; Tschopp et al., 2011).

However, most power training studies used pneumatic machines for power or high-velocity training (Balachandran et al., 2014; Cress et al., 2005; Cuoco et al., 2004b; Fielding et al., 2002; Marsh et al., 2009; Reid et al., 2008; Reid et al., 2015). Pneumatic machines use compressed air instead of weight plates for resistance, and are therefore specifically designed to perform high-velocity training in a relatively safe environment. But these machines are often limited to research facilities due to their high cost and the need for special support equipment, such as a dedicated compressor and pneumatic lines. The general public, on the other hand, commonly has access only to conventional plate-loaded machines, which are not designed for power training. Although power training studies using conventional plate-loaded machines have become more common in recent years (Correa et al., 2012; Glenn et al., 2015; Ramirez-Campillo et al., 2014), the effectiveness and safety of power training using plate-loaded machines compared to pneumatic machines remains uncertain.

Acute exercise conditions have shown that pneumatic machines are superior to standard plate-loaded machines when examining certain neuromuscular variables. For example, Napoli et al. (2015) showed that when using EMG (Electromyography) wavelet analysis, power training on pneumatic machines evoked greater EMG energy during eccentric and concentric contractions than plate-loaded machines during a leg extension exercise. Peltonen et al. (2013) showed that compared to standard plate-loaded machines, pneumatic machines generated lower levels of peripheral and central fatigue. These acute results indicate that pneumatic machines could be superior to plate-loaded machines in improving performance in older adults. However, to our knowledge, no long-term study has compared the effects of power training using pneumatic and standard resistance training machines on power, physical function and adverse effects in older adults.

In light of the benefits of power training in older adults and the paucity of studies comparing power training using pneumatic and plate-loaded machines, the purpose of this study was to assess changes in power, physical function, and adverse effects of high-velocity training using plate-loaded compared to pneumatic machines. We hypothesized that pneumatic machine training would be superior to plate-loaded machine training for increasing power, physical function, activities of daily living and self-reported function while the plate-loaded machine training would produce greater improvements in muscle strength.

1. Materials & methods

1.1. Study design

The study employed a 12-week randomized, controlled, single-blind design to assess neuromuscular performance, body composition and IADL function in independently living older persons. A CONSORT flow diagram of the study is presented in Fig. 1.

1.2. Participants

Participants were recruited from the local South Miami community using flyers, posters, and advertisements in newsletters. We also used an internal database that contained names of older adults interested in participating in research. Additionally, participants were recruited by posting an advertisement in the local newspaper. The criteria for inclusion were that volunteers should be between 60 and 90 years of age, live independently in the community, not have regularly participated in a structured exercise program using weights in the past six months, be planning to reside in the area for the duration of the study, and be able to communicate and read in English. Exclusion criteria included neurological impairments that would affect balance, severe cognitive impairment (Mini-Mental State Examination score of 19 or below), severe musculoskeletal impairment, unstable chronic disease state, major depression, severe vestibular problems, severe orthostatic hypotension, simultaneous use of cardiovascular, psychotropic and antidepressant drugs as reported by the subjects, and active participation in a resistance or balance training program. The protocol was approved by the University's Institutional Review Board and all participants signed an informed consent prior to participation.

Using a computer-generated randomization list, participants were stratified based on the absolute lower body power using a 1:1 allocation with a random block size of 2, 4 or 6 into either the plate-loaded (PL) or pneumatic (Pn) training group. To ensure concealment of group allocation, randomization and group allocation were implemented by personnel not otherwise involved in the study or the recruitment of subjects.

1.3. Intervention

The duration of the program was 12 weeks and the participants engaged in a full-body workout twice per week. After randomization and prior to the start of training, training loads were determined by finding the 10-repetition load reported to be at a moderate intensity for each subject on each exercise using a rating of perceived exertion (RPE) of 5–6 on a 10-point scale.

Within the 12-week training period, participants went through a 2-week preparatory phase during which the volume was gradually increased from 1 set to 3 sets. Subsequently, each training session began with 1 set of warm-up at 50% of the set workload for 8–10 repetitions on two multi-joint upper body and lower body machines. The warm-up sets were used throughout the duration of 12 weeks. The intensity, volume, and progression of training were based on the current resistance training guidelines recommended by the American College of Sports Medicine (Garber et al., 2011):

- the intensity ranged from a moderate intensity (6–8) on an RPE scale of 0–10 and a volume of 3 sets of 10 repetitions;
- participants performed the concentric phases of each exercise as fast as possible and the eccentric phase in 2 s;
- load was increased by 5 to 10% when participants could perform 3 sets of 10 repetitions with proper form while reporting an RPE of < 6;
- the repetition range was reduced to 8 repetitions rather than 10 after eight weeks;
- periodization of load (increase in intensity and decrease in volume) during the final weeks ensured progression throughout the duration of the study (American College of Sports Medicine et al., 2009);
- a one minute recovery was provided between sets; and,
- both groups performed five lower body and six upper body exercises targeting the major muscle groups as shown in Appendix as Table A.1.

The PL group performed all the exercises using conventional plate-loaded resistance machines (VR2: Cybex International, Inc., Medway, MA, USA), while the Pn group performed all exercises using pneumatic machines (Keiser A420, Keiser Sports Health Equipment, Fresno, CA). Both groups performed exercises targeting similar muscle groups. Each session ended with a 5 min cool down involving stretching exercises and light calisthenics. The training sessions were supervised by a minimum of two trainers. All trainers were exercise physiology majors who received comprehensive preparation prior to the start of the study.

1.4. Primary outcomes

Subjects and trainers were not aware of the hypotheses being tested. Testers were blind to group assignments.

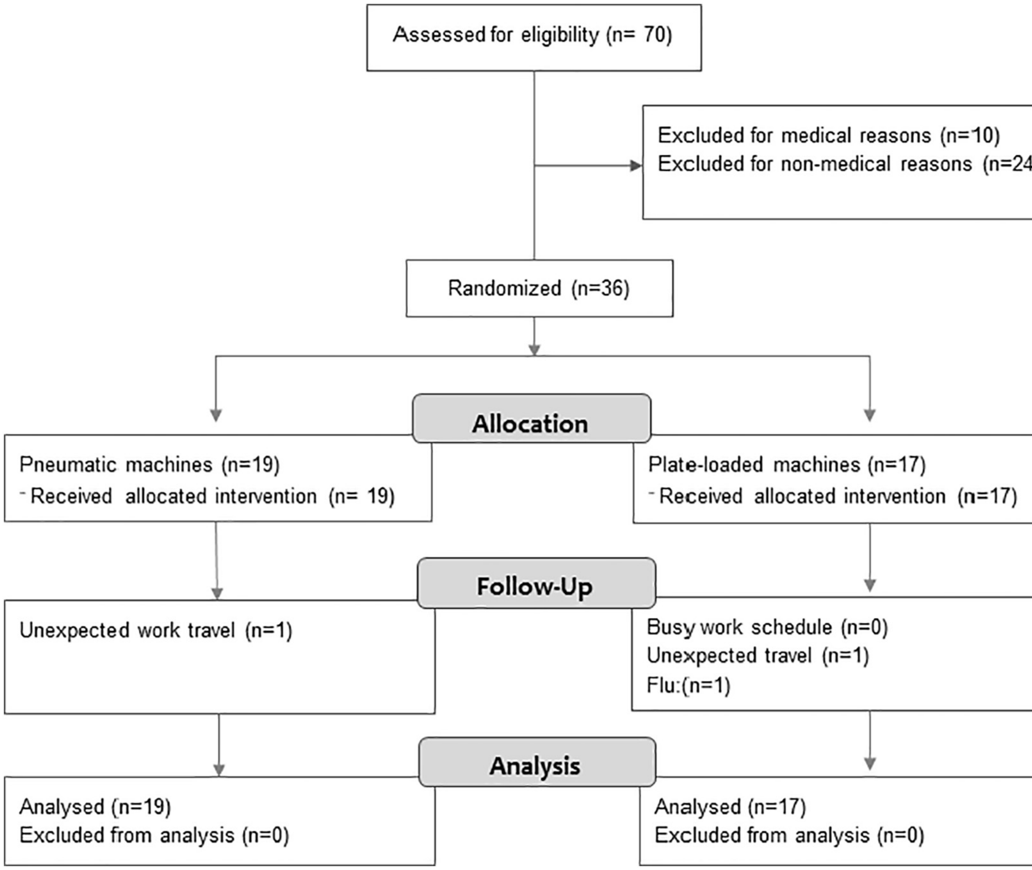

Fig. 1. CONSORT participant flow diagram.

1.4.1. *Upper body and lower body power testing*

Chair stands using a linear transducer (TENDO Sports Machines; Trencin, Slovak Republic) were used to assess lower body peak power. Chair stand power using a Tendo Weight Lifting Analyzer has been shown to be valid, reliable and sensitive to change due to training (Glenn et al., 2015; Gray and Paulson, 2014). The highest peak power across five chair stands with 1 min of rest between stands was used for statistical analysis.

The seated medicine ball throw test was used to assess upper body power. The test has been shown to be valid, reliable, and safe for measuring upper body power in older adults (Harris et al., 2011). The score is the horizontal distance participants can propel a 3 kg ball without trunk flexion. The chair stand and medicine ball throw were chosen as tests for upper body and lower body muscle power instead of the pneumatic or plate-loaded chest or leg press machines, since improvements seen on either machine might be biased in favor of the machine used during training.

1.5. *Secondary outcomes*

1.5.1. *Physical function measure*

The Physical Performance Battery (PPB) was chosen to detect performance changes since it is specifically designed for well-functioning older adults. The battery includes balance (tandem stance, semi-tandem and single leg stance), five chair stand, normal gait speed, and narrow walk. The PPB modifies an established performance battery, namely the Short Physical Performance Battery (SPPB), by adding more challenging tasks, the single leg stance and narrow walk (Simonsick et al., 2001). In addition, estimates of meaningful or clinically significant changes in PPB have been previously reported (Perera et al., 2006).

1.5.2. *Upper body and lower body muscle strength*

The 30-second Arm Curl is a general measure of upper body muscle strength. The score is the total number of arm curls (5 lb dumbbell for women, 8 lb dumbbell for men) performed through a full range of motion in 30 s. A moderate to high correlation (0.84 for men and 0.79 for women) was observed between the arm curl test and a composite measure of upper body muscle strength that included the one-repetition maximum (1RM) for bicep, chest, and upper back muscle strength (Rikli and Jones, 1999).

The 30-Second Chair Stand test was used to measure lower body muscle strength. Studies have shown that chair stand performance correlates well with other indicators of lower body muscle strength (knee extensor muscle strength, knee flexor muscle leg strength and 1RM leg press muscle strength) and functional measures such as stair climb speed, walking speed, and risk of falling (Jones et al., 1999). The score is the total number of times that an individual can rise from a seated to a full stand position without pushing off with their arms.

1.5.3. *Activities of daily living*

The timed up and go (TUG) is a test to assess dynamic balance, fall risk and agility. It has been shown to be well correlated to the Berg balance score (r = 0.81), gait speed (r = 0.60), and the Barthel index of ADL's (r = 0.78) (Podsiadlo and Richardson, 1991). Two trials were performed with the shorter time used for analysis.

The gallon-jug shelf-transfer test is designed to mimic an important activity of daily living, the transfer of a moderately heavy object. The test has been shown to be valid, reliable, and responsive in elderly population (Signorile et al., 2007). Each participant was asked to sequentially transfer five 1-gallon jugs as quickly as possible from a lower shelf, aligned with the participant's patella, to a higher shelf placed at the level of the top of the participant's shoulder. Two trials were provided with a 1-minute recovery between trials.

1.5.4. Self-reported physical function questionnaire

It is now known that self-report assessment and performance assessment of physical function are distinct, yet complementary concepts and both have their own advantages and disadvantages. The Patient Reported Outcomes Measurement Information System (PROMIS) physical function questionnaire uses item response theory (IRT) and computer-aided testing (CAT) to improve precision and quality and has been shown to be reliable and valid in a large sample of the general population (Fries et al., 2014). In addition, a novel online video questionnaire was used to assess physical function in the participants (Balachandran et al., 2016). The questionnaires were administered using our laboratory computers.

1.5.5. Ratings of perceived exertion (RPE)

Ratings of perceived exertion (RPE) have been assessed for the total body and the active muscles to track resistance training progressions and prescribe training intensities (Gearhart et al., 2009). The OMNI (omnibus) scales include mode specific pictorials, numerical ratings, and corresponding verbal descriptions that are distributed along an increasing intensity gradient thus making the scale easier to interpret (Robertson et al., 2003). Ratings of perceived exertion (RPE) were recorded for each participant after their cool down and after each exercise to track weight progressions.

1.5.6. Adverse effects

Reporting of adverse events was based on the four types of events (falls, cardiovascular-related episodes, musculoskeletal-related events, and health care) suggested by the Behavior Change Consortium (BCC) of the NIH when reporting trial results for physical activity interventions (Ory et al., 2005). Since most adverse events in resistance training studies are musculoskeletal in nature, we chose to further refine the classification of severity of musculoskeletal events as reported by the BCC.

1.6. Statistical analysis

An analysis of covariance (ANCOVA) was used to examine between group differences using baseline values as a covariate. All significance tests were two-tailed and an alpha level of 0.05 was required for significance. Data were analyzed using an intention-to-treat approach (ITT), in which participants were grouped according to randomized assignment. Adjusted means and pooled SD as a standardizer were used to calculate Cohen's *d*. All statistical analyses were performed using SPSS, version 22 statistical package (IBM SPSS Statistics, Armonk, NY).

For the primary outcome of lower body power, a large effect size of 0.8 was chosen to calculate sample size. To our knowledge, there is no clinically meaningful cut-off reported for power in healthy older men. Taking into account the cost and special requirements of pneumatic machines, a large effect size difference can only justify the use of pneumatic machines. Thus based on a 5% two-sided significance level and power of 80%, a sample size of 26 was required for each group. Using a correlation of 0.80 obtained between pretest and post-test during comparisons of functional variables in our previous studies, we applied the 'design factor (correction factor)' for ANCOVA (Borm et al., 2007). Using an ANCOVA improves the precision of the estimate and considerably lowers the sample size requirement. After using the correction factor, the sample size was reduced to 16 per group. Accounting for a 10% drop out rate, a conservative estimate for this type of study in our laboratory, the final sample size calculated was 18 per group.

2. Results

As shown in Fig. 1, 36 subjects were recruited and randomized into two groups: 19 in the pneumatic group (Pn) and 17 in the plate-loaded group (PL). Baseline characteristics were similar in the groups and are shown in Table 1.

Table 1
Baseline characteristics of study participants.

Characteristics	Pneumatic (n = 19)	Plate-loaded (n = 17)
Age, y	68.9 ± 4.9	68.8 ± 5.0
Gender	12F (63%)	8F (47%)
Body composition		
Weight, kg	79.1 ± 19.0	75.6 ± 10.3
Height, cm	165.7 ± 9.1	168.2 ± 9.2
BMI, m/kg^2	27.9 ± 6.5	27.6 + 3.5
Body fat, %	35.7 ± 8.8	34.7 ± 7.6
Power		
Medicine ball throw, m	3.2 ± 0.9	3.2 ± 1.0
Chair stand peak power, W	935.9 ± 240.8	927.1 ± 313.3
PPB	2.6 ± 0.3	2.4 ± 0.4
Self-reported function		
PROMIS	51.6 ± 7.7	50.8 ± 6.0
Video questionnaire	271.2 ± 54.4	280.0 ± 44.5
MMSE (0 – 30)	29.6 ± 1.2	29.7 ± 1.2

PPB: physical performance battery; MMSE: mini–mental status examination.
Values are mean ± SD unless noted otherwise.

2.1. Adherence to intervention

Intervention adherence (the number of sessions attended / total session ∗ 100) for the Pn group was 84% (SD, 16%) and for the PL group was 87% (SD, 10%).

2.2. Adverse events

As shown in Appendix Table A.2, there were no serious adverse events in any of the categories. All events were reported as either possibly related or not related to the intervention, and musculoskeletal events were the most common.

2.3. Primary outcomes

Results for upper and lower-body peak power are shown in Table 2. The chair stand peak power showed no significant difference between groups (MD = 113.7 W, 95% CI (−293, 65); p = 0.21); however, there was a small effect size (d = 0.4, 95% CI (−1.1, 0.3)) favoring the PL group. Analysis of unadjusted means for peak power did not change the outcomes, once again showing a small effect size (d = 0.4, 95% CI (−1.0, 0.3), p = 0.46). Both the Pn group (d = 0.7, p = 0.007) and the PL group (d = 0.9, p = 0.001) showed improvements. Pn showed a 174 W (19%) increase in peak power, while PL showed a 287 W (31%) increase.

For the medicine ball throw, there was no significant difference between the groups (MD = 0.1, 95% CI (−0.3, 0.1); p = 0.35). For within-group changes, Pn (d = 0.1, p = 0.18) showed no significant improvement, while PL (d = 0.2, p = 0.001) did improve significantly. Pn showed a 0.1 m (3%) increase; while PL showed a 0.2 m (6%) increase. Using a per-protocol analysis to estimate the effect of received treatment did not change the results as shown in Appendix in Table A.3.

2.4. Secondary outcomes

2.4.1. Muscle strength

Results for secondary outcomes are also presented in Table 2. Upper body and lower body muscle strength assessed using the 30-second arm curl and 30-second chair stand tests, respectively, showed no significant difference between groups. However, both arm curls (d = 0.3, 95% CI (−0.9, 0.4), p = 0.33) and chair stand d = 0.2, 95% CI (−0.8, 0.5), p = 0.5 showed a small effect size favoring the PL group. For within-group improvements in arm curls, both Pn (d = 0.9, p < 0.001) and PL (d = 1.4, p < 0.001) showed significant improvements. For 30-

Table 2
Raw, adjusted means and effect sizes for primary and secondary outcomes.

	Pneumatic (n = 19)		Plate (n = 17)		Adjusted mean at 12 weeks (*SE*)		Adjusted mean difference 95% CI	p	Effect size Cohen's *d* 95% CI
	Mean (*SD*)		Mean (*SD*)						
	Baseline	12 weeks	Baseline	12 weeks	Pneumatic	Plate			
Power									
Peak power, W	926.4 (244.1)	1110.7(333.4)*	927.1 (313.2)	1214.1 (493.2)*	1105.8 (60.5)	1219.6 (64.0)	− 113.7 (− 293, 65)	0.21	0.4 (− 1.1, 0.3)
Ball throw, m	3.2 (1.0)	3.3 (1.0)	3.2 (1.0)	3.4 (1.1)*	3.27 (0.1)	3.36 (0.1)	− 0.1 (− 0.3, 0.1)	0.35	
Muscle strength									
Arm curls	20.4 (4.0)	24.0 (5.3)*	17.6 (3.0)	21.8 (4.1)*	22.47 (0.7)	23.43 (0.7)	− 1.0 (− 0.2.9, 1.0)	0.33	0.3 (− 0.9, 0.4)
30 s chair stand	14.6 (2.8)	17.2 (4.1)*	14.3 (3.4)	17.4 (4.5)*	16.98 (0.6)	17.54 (0.6)	− 0.6 (− 2.2, 1.1)	0.50	0.2 (− 0.8, 0.5)
PPB									
PPB total	2.6 (0.3)	2.9 (0.4)*	2.4 (0.4)	2.7 (0.4)*	2.85 (0.1)	2.81 (0.1)	0.05 (− 0.1, 0.2)	0.60	
Normal walk, s	5.3 (1.1)	4.7 (1.1)*	4.9 (0.5)	4.6 (0.7)	4.6 (0.2)	4.7 (0.2)	− 0.1 (− 0.60, 0.47)	0.80	
Narrow walk, s	5.3 (2.1)	4.8 (1.3)	4.8 (1.9)	4.6 (0.7)	4.8 (0.3)	4.6 (0.3)	0.2 (− 0.6, 0.9)	0.60	
Chair stand, s	10.3 (1.9)	8.7 (1.7)*	10.9 (2.8)	8.9 (2.9)*	8.9 (0.3)	8.7 (0.3)	0.2 (− 0.6, 1.0)		
Balance, s	75.9 (13.4)	85.9 (7.7)*	77.6 (17.9)	75.9 (17.9)	86.4 (2.4)	75.4 (2.5)	10.9 (3.8, 18.1)	0.004	0.7 (0.1, 1.4)
Activities of daily living									
Jug transfer, s	9.1 (1.3)	8.4 (1.4)*	9.0 (1.2)	8.1 (1.2)*	8.34 (0.2)	8.17 (0.2)	0.2 (0.3, 0.6)	0.43	
Get up & go, s	5.8 (0.9)	5.3 (0.9)*	5.5 (0.7)	5.0 (0.9)*	5.17 (0.1)	5.09 (0.1)	0.1 (− 0.3, 0.4)	0.64	
Self-reported measures									
PROMIS	51.6 (7.7)	52.4 (6.6)	50.1 (6.0)	51.1 (5.7)	52.1 (0.8)	51.4 (0.9)	0.7 (− 1.7, 3.2)	0.54	
Video questionnaire	274.4 (54.5)	290.8 (63.4)	280.0 (44.5)	311.0 (56.3)*	294.4 (11.0)	308.3 (10.8)	− 12.5 (− 43.2, 18.1)	0.41	0.3 (− 0.9, 0.4)
Session RPE		5.9 (0.4)		5.7 (0.3)			0.1 (− 0.1, 0.4)	0.30	0.4 (1.1, 0.5)

PPB: physical performance battery; RPE: rate of perceived exertions; PROMIS: patient reported outcome measures information system. Absolute between-group differences, Cohen's *d*, p values and 95% confidence interval (CI) are derived from analysis of covariance, adjusted for baseline level. Effect size of d = 0.80 or reater is considered large, 0.50 to 0.79 is considered medium, and 0.20 to 0.49 is considered small. Only effect size equal or > 0.2 reported.

* $p < 0.05$.

second chair stand, both Pn (d = 0.9, $p < 0.001$) and PL (d = 0.9, $p < 0.001$) showed significant within-group improvements.

2.4.2. Physical performance battery (PPB)

PPB showed no significant difference between the groups, for changes within the group, both Pn (d = 1.2, $p < 0.001$) and PL (d = 0.8, $p < 0.001$) showed significant improvements. For the components of the PPB, total balance showed a statistically significant and moderate effect size (d = 0.7, 95% CI (− 0.6, 1.4), p = 0.004) in favor of Pn compared to PL. Normal, narrow walk and 5 chair stands showed no significant differences between the groups.

2.4.3. Activities of daily living (ADL)

For ADL, there were no significant between-group differences. For within-group changes, the gallon jug transfer for Pn (d = 0.5, p = 0.001) and PL (d = 0.7, $p < 0.001$) and TUG Pn (d = 0.5, $p < 0.001$) and PL (d = 0.8, p = 0.001) showed significant improvements. For self-reported function analysis using PROMIS and online video questionnaire no significant differences between the groups were seen. For within-group changes, only the PL group showed a significant improvement in the video questionnaire (d = 0.7, p = 0.02)

2.4.4. Training changes in muscle strength and power

Between-group analyses, revealed no significant differences across the training period for chest press (MD = 1.0, 95% CI (− 8, 10)) and for leg press (MD = 5.0, 95% CI (− 28, 38)). Weekly changes in power for the Pn group are shown in Appendix Fig. A.1. The average increase in power from week 3 to week 12 for the leg press and chest press were 228 W ± 80.8, $p < 0.001$ and 48 W ± 20.3, p = 0.01, respectively. Power progressions could only be tracked on the pneumatic machines, since these machines are equipped with sensors to assess power. The average RPE tracked for leg press (Pn: 5.7 ± 0.31; PL: 5.7 ± 0.23) and for chest press (Pn: 5.9 ± 0.31; PL: 5.8 ± 0.36) for the duration of 12 weeks suggests a moderate level of effort as intended. In addition, session RPE showed no significant difference between the groups.

3. Discussion

This study showed that after 12 weeks of power, or high-velocity, training there was no significant difference in power increases produced using Pn and PL machines. To our knowledge, this is the first trial to compare the effectiveness of Pn to traditional PL machines in improving power and physical function.

For the primary outcome of lower body peak power, the Pn group showed a significant 19% increase, while the PL showed a significant 31% increase. These results are consistent with those reported in other power training studies. Studies lasting 16 weeks or more showed large increases in power ranging from 50 to 98% (Fielding et al., 2002; Henwood et al., 2008; Reid et al., 2015; Sayers et al., 2003). However, similar to the current study, the majority of the short term (12–15 weeks) studies showed power change between 10 and 41% (Balachandran et al., 2014; Bottaro et al., 2007; de Vos et al., 2005; Marsh et al., 2009; Reid et al., 2008; Sayers and Gibson, 2010). These studies used both pneumatic and plate-loaded machines for training. Notably, most of these power training studies measured power using the same leg press or leg extension machine used during the training intervention (Balachandran et al., 2014; Bottaro et al., 2007; de Vos et al., 2005; Marsh et al., 2009; Reid et al., 2008; Sayers and Gibson, 2010). Consistent with specificity theory, studies that showed the least improvements in power, ranging from 8% to 22%, used tests that were not part of the training intervention. For example, studies using counter movement jump (CMJ) as a measure of lower body power, while using plate loaded machines for the intervention, reported increases in power of 17.5% to 22% (Beltran Valls et al., 2014; Correa et al., 2012; Ramirez-Campillo et al., 2014). Similarly, a study that used chair stands to measure power and plate-loaded machines for training showed a 10% increase in power (Glenn et al., 2015). The current study used machines for training and tested power using exercises that were not part of the intervention. Thus, the power improvement observed in the current study is similar to other power training studies using a comparable modality of training and testing.

For upper body power measured by the medicine ball throw, the Pn showed a non-significant 3% increase, while the PL groups showed a significant 6% increase. Two studies reported increases in medicine ball throw ranging from 15% to 21% (Correa et al., 2012; Ramirez-Campillo et al., 2014). However, these studies included medicine ball throws as part of the intervention, bringing into question whether this large increase may have been the result of utilizing a training exercise as a testing tool. As shown in Appendix Fig. A.1, the training improvement in power at 10 weeks was 228 W for leg press and 48 W for chest press. This is similar to a previous study conducted in our lab across a 10-week training period (Leg press: 205 W, Chest Press: 37 W) (Balachandran et al., 2016). Likewise, Feilding et al. (Fielding et al., 2002) showed a similar increase in leg press training power of 277 W in 10 weeks.

Muscle strength, as measured by 30-second chair stand and arm curl tests, showed no statistically significant differences between the groups; but significant within-group improvements were seen for both 30 s chair stand (Pn = 17.4%; PL = 21.4%) and arm curl (Pn = 17.7%, PL = 24.1%). Ramirez-Campillo et al. (2014) reported a 21% increase in chair stands after a 12 week study while Correa et al. (2012) observed an 8% improvement in a 6 week intervention. For PPB, both groups showed statically significant and clinically meaningful improvements (CMI) of 0.3 points (CMI for PPB = 0.23 points). For the components of PPB, however, balance showed a statistically significant between-group difference and a moderate effect size in favor the Pn group. Studies have shown lower loads emphasizing velocity have a greater influence on low force task's such as walking and balance, than on muscle strength-dependent tasks such as stair climbing or rising from a chair (Cuoco et al., 2004a; Orr et al., 2006; Sayers et al., 2005). Consistent with this hypothesis, despite similar improvements in power for 20, 40 and 80% 1RM, balance showed the greatest improvement using low loads (Orr et al., 2006). The greater improvement observed in chair stand and arm curl muscle strength in the PL group suggests that the improvement in chair stand power in the PL group could be largely due to increase in the force rather than the velocity component of the power equation.

Activities of daily living measured by gallon jug transfer and TUG, showed significant improvements of 10–15% in both groups, similar to other power training studies that have reported 11–18% improvements in TUG after power training (Bottaro et al., 2007; Ramirez-Campillo et al., 2014; Ramirez-Campillo et al., 2016) Self-reported measures assessed by the PROMIS and video questionnaire showed no significant difference between the groups. PROMIS showed 1–2% and the video questionnaire showed a 7–11% improvement. Other studies which have assessed changes in self-reported function in response to power training have shown a modest 4–14% improvement in mobility-limited older adults (Bean et al., 2009; Marsh et al., 2009).

Overall intensity was maintained at approximately 6 RPE (0–10 scale) and showed no significant difference between the groups. These results imply that any differences in power, physical function and ADL's between groups should not be attributed to differences in effort or intensity between groups.

Self-reported adverse events were either 'possibly related' or 'not related' to the intervention. None of the events was reported as 'definitely related'. In addition, there were no serious adverse events reported for any of the categories. Most of the musculoskeletal events reported were due to existing injuries, such as shoulder and knee pain. Intervention adherence was approximately 85% for both groups, showing that the program was well tolerated by both groups.

To analyze non-inferiority, we chose a non-inferiority (NI) margin of half the effect size of the ES used to calculate sample size, which comes to 0.4 ES. The 95% CI for the current study based on ITT analysis is (− 1.1, 0.3) and per protocol analysis is (1.0, 0.5). Considering a one-sided 95% CI, the upper limit in favor of pneumatics is 0.2 for the ITT analysis and 0.4 for the per protocol analysis. Consequently, the CI limit lies within the NI margin and non-inferiority can be inferred. Nevertheless, since the non-inferiority margin was not pre-specified, non-inferiority should be interpreted accordingly.

3.1. Muscle strength & limitations

The muscle strengths of the study included using a blinded assessor for testing for all outcomes including adverse events, analysis using an intention-to-treat approach, and a pragmatic approach to selecting and progressing weights. Blinding is a widely recommended strategy to reduce bias in scientific trials, particularly when assessing subjective outcomes (Wood et al., 2008). Trials that used blinded assessors tend to report smaller effect sizes than do those that used un-blinded assessors (Liu et al., 2011). An ITT analysis is considered the best analysis for a superiority trial (Lewis and Machin, 1993). To our knowledge, this is the first power training trial to use an ITT approach. The study used a pragmatic approach by employing RPE for selecting training loads and using both RPE and repetitions completed for increasing the load throughout the training period. Most studies determined training loads using a 1RM protocol and progressed weights either by testing 1RM every 2–4 weeks or based solely on repetitions completed. Selecting and progressing training loads using both a subjective scale like RPE and an objective criteria of repetitions completed could be beneficial in improving adherence in a population prone to frequent joint discomfort and muscle pain.

The limitations of the study included the duration of the study, the population assessed, and the lack of a control group. The intervention period was only 12 weeks, and the population included only healthy community-living individuals. The majority of resistance training studies in older adults are 8–12 weeks in duration. We acknowledge that the duration of 12 weeks is short, and may not accurately assess compliance and adverse effects of a training program. Because the study used older adults who were living independently in a community, the results may not be applicable to older adults with functional limitations or those living in extended care facilities. Although the study showed similar improvements compared to other studies and used blinded assessors, the study lacked a control group. Nevertheless, studies with similar duration and population that used a control showed very small and negative changes in the control group. For example, studies employing a control group showed power changes in the range of − 2% to 1.4% for lower body power using CMJ, − 0.8% to − 5.6% for upper body power using chest press and medicine ball throw, − 1.6% for chair stands, and 1.2% for TUG (Beltran Valls et al., 2014; Ramirez-Campillo et al., 2014).

3.2. Conclusion

After 12 weeks of power training, the current study showed that pneumatic machines, which are specifically designed to perform power training, were not superior to conventional plate-loaded machines for improving power and physical function. Both groups showed improvements in lower body power and physical function. Considering the simple modification required to perform power training, the lack of adverse events, and the improvements seen in power and physical function, the study suggests that power training can be performed safely and effectively using either pneumatic machines or plate-loaded machines among older adults.

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Appendix A

Table A.1
List of exercises.

Upper body	Lower body
Chest press	Leg press
Seated rows	Leg curl
Shoulder press	Calf raises
Lat pulldowns	Hip abduction
Biceps curl	Hip adduction
Triceps pushdowns	

Table A.2
Adverse events classification.

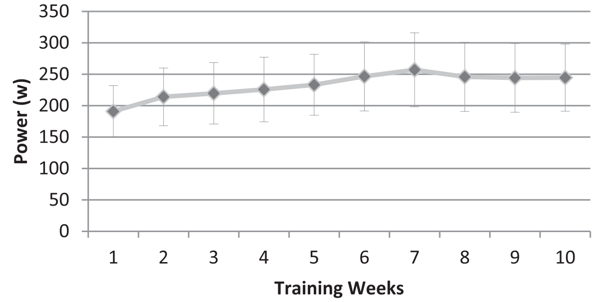
	Pneumatic (n = 19)			Plate (n = 17)		
	Mean (*SD*)			Mean (*SD*)		
	Severe	Moderate	Mild	Severe	Moderate	Mild
Musculoskeletal		3	3		1	1
Cardiovascular			1			
Falls					1	2
Health care utilization		1	2			1
Total		4	6		2	4

All adverse events listed were self-reported as 'related' or 'not related' to the intervention.
Musculoskeletal adverse event classification: mild event is any event that requires the participant to lower the exercise volume for the specific muscle group for at least 2 weeks; moderate event is any event that requires discontinuing the exercise for the specific muscle for at least 2 weeks; severe event is any event that requires the participant to withdraw from the study.

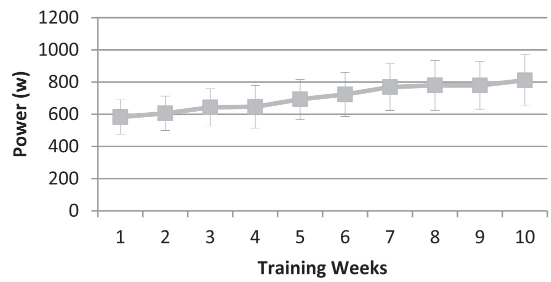
Table A.3
Per protocol analysis table.

	Pneumatic (n = 16)	Plate (n = 12)		Adjusted mean at 12 weeks (*SE*)			Adjusted mean difference 95% CI	p	Effect size Cohen's *d* 95% CI
	Mean (*SD*)	Mean (*SD*)							
	Baseline	12 weeks	Baseline	12 weeks	Pneumatic	Plate			
Power									
Peak power, W	971.8 (217.1)	1180.4 (287.8)*	947.2 (327.4)	1216.6 (468.7)*	1170.1 (68.1)	1230.4 (78.6)*	− 60.3 (− 275.0, 154.0)	0.56	0.2 (− 1, 0.5)
Ball throw, m	3.3 (1.0)	3.5 (1.0)	3.2 (1.1)	3.4 (1.1)*	3.4 (0.1)	3.5 (0.1)*	− 0.60 (− 0.3, 0.2)	0.61	

Absolute between-group differences, Cohen's *d*, p values and 95% confidence interval (CI) are derived from analysis of covariance, adjusted for baseline level.
Effect size of d = 0.80 or greater is considered large, 0.50 to 0.79 is considered medium, and 0.20 to 0.49 is considered small. Only effect size equal or > 0.2 reported.
Excluded drop outs and subjects who missed > 25% of the sessions.
* $p < 0.05$.



Chest press power changes (week 3 - week 12) with 95% CI for the pneumatic group (n =17)



Leg press power changes (week 3 - week 12) with 95% CI for the pneumatic group (n=17)

Fig. A.1. Weekly changes in power for the pneumatic (Pn) group.

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