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Effects of Movement Velocity and Training Frequency of Resistance Exercise on Functional Performance in Older Adults: A Randomised Controlled Trial

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Abstract

Objectives: To investigate the effects that high-velocity, low-load (HVLL) and low-velocity, high-load (LVHL) resistance exercise, performed once or twice-weekly, have on indices of functional performance (primary outcome), maximal strength, and body composition (secondary outcomes) in older adults. **Methods:** In a randomised, controlled, multi-armed, parallel design, 54 moderately-highly active, but resistance exercise naïve older adults (aged 60-79 years), attended baseline and post-10-week intervention assessment sessions. Physical and functional assessments were completed, and predicted one-repetition maximums (1-RM) were obtained for eight exercises. Participants were then randomised into one of five conditions: HVLL once-weekly (HVLL1: n=11) or twice-weekly (HVLL2: n=11), LVHL once-weekly (LVHL1: n=10) or twice-weekly (LVHL2: n=11), no-exercise control condition (CON: n=11). The HVLL conditions completed 3 sets of 14 repetitions at 40% 1-RM and the LVHL conditions, 3 sets of 7 repetitions at 80% 1-RM. In total, 50 participants completed all testing and were included in analyses. **Results:** Only LVHL2 improved 30-sec chair stand performance (p=0.035; g=0.89), arm curls (p=0.011; g=1.65) and grip-strength (p=0.015; g=0.34) compared to CON. LVHL2 improved maximal strength compared to CON for 7/8 exercises (p<0.05). Whereas, LVHL1 and HVLL2 only improved seated row and chest press compared to CON (p<0.05). **Conclusion:** Possibly due to the lower intensity nature of the HVLL conditions, LVHL, twice-weekly was most beneficial for improving functional performance and strength in moderately-highly active older adults. Therefore, we recommend that exercise professionals ensure resistance exercise sessions have sufficient intensity of effort and volume, in order to maximise functional performance and strength gains in older adults.

Keywords: Muscle Strength; Ageing; Power Training; Strength Training; Exercise Interventions

Introduction

Ageing is characterised by the progressive loss of muscle mass, muscle strength, and decline of functional performance (Barber et al., 2015), facilitated by physiological and structural alterations such as: type II myofibre atrophy, altered hormone status, protein synthesis and muscle architecture (Raj et al., 2010). Consequently, the ability to complete activities of daily living becomes impaired, reducing the independence and quality of life of older adults (Doherty, 2003).

However, resistance exercise can attenuate losses of strength, power, muscle mass and functional performance in older adults (Raj et al., 2010). Recently, high-velocity, low-load (HVLL) and low-velocity, high-load (LVHL) resistance exercise, targeting opposite ends of the force-velocity curve (methods of power and strength training) have been extensively investigated (Cadore et al., 2014). As muscle power better predicts performance in activities of daily living than strength (Beltran Valls et al., 2014) and muscle power recedes faster than strength (de Vos et al., 2005), developing/maintaining peak power is key for retaining function and independence in older adults (Bean et al., 2002). However, Fisher et al. (2017) recommended that explosive movements should be avoided during resistance exercise. A subsequent commentary by Cadore et al. (2018) strongly rebutted these claims, evidencing that despite a plethora of investigation, there is still no definitive recommendation for resistance exercise prescription in older adults.

Physical activity guidelines in the United Kingdom, recommend that older adults perform whole-body strength training at least twice-weekly. However, in addition to older adults indicating a preference for once-weekly resistance exercise over twice or thrice-weekly (Foley et al., 2011), many need supervision to attain substantial benefits from resistance exercise (Ramirez-Campillo et al., 2017), meaning cost may be a significant barrier. Therefore, it would be beneficial to understand the minimal effective dose of resistance exercise that facilitates physiological and functional benefits. Previous studies have demonstrated that once-weekly resistance exercise can improve strength and/or functional performance (Foley et al., 2011; Taaffe et al., 1999) and Fisher et al. (2017) proposed that as little as 10 and 30 minutes resistance exercise, twice-weekly may be sufficient to obtain considerable physiological and psychological benefits. Furthermore, Byrne et al. (2016) advocated investigation into the minimal effective training dose of resistance exercise (training volume and/or frequency) for older adults. Therefore, the objectives of the present study were to investigate the effects that supervised programmes of HVLL and LVHL performed once or twice-weekly, have on indices of functional performance (Primary outcomes), maximal strength, and body composition (secondary outcomes). As Gentil et al. (2017) suggests that the use of heavy relative loads, performing exercise at high movement velocity, or training to momentary failure stimulates type II fibres, ultimately improving strength and the ability to carry out activities that require speed/power. We hypothesise that: 1) HVLL and LVHL will similarly impact maximal strength and functional performance and 2) due to greater exercise volume, improvements will be enhanced in the twice-weekly, compared to the once-weekly conditions.

Methods

Design

A 10-week, randomised, controlled, multi-armed, parallel study was conducted to determine to the effects of HVLL and LVHL, performed once or twice-weekly on functional performance, maximal strength and body composition. Participants were randomised (1:1 ratio) by an independent researcher using minimisation, to ensure small variances in sex and age between conditions. Participants and researchers were not blinded, as exercise conditions were apparent, and the same researcher carried out baseline, post-intervention testing and all intervention sessions. No methodological changes were made prior to commencement. Institutional ethics approval was obtained, and all participants were made aware of the exercise conditions before providing informed consent.

Participants

Through self-selection, 54 community-dwelling, Caucasian, males and females (Table 1) were recruited between March 2017 and November 2017 in Coventry, United Kingdom. The CONSORT diagram (Supplementary Figure 1) shows 50 participants completed all assessments and were included in analyses. Prior to randomising, each participant met specific eligibility criteria: (a) absence of cognitive impairment (b) absence of acute or terminal illness, myocardial infarction, symptomatic coronary artery disease, congestive heart failure, neuromuscular disease, or uncontrolled hypertension (>150/90 mmHg), (c) no upper or lower extremity fracture in the previous six months, (d) no resistance exercise in the previous six months (e) aged 60 years or older. Minimisation was used to assign one of the following experimental conditions, after the first participant in each condition was truly, randomly allocated: (1) high-velocity, low-load once-weekly (HVLL1) (2) low-velocity, high-load once-weekly (LVHL1) (3) high-velocity, low-load twice-weekly (HVLL2) (4) low-velocity, high-load twice-weekly (LVHL2) (5) no exercise control condition (CON). All functional assessments took place in a private strength and conditioning suite and each exercise session at Coventry university gym.

Physical assessments

Height (cm) was measured using a stadiometer (Seca Instruments, Hamburg, Germany). Body mass, body composition, fat free mass (FFM) and fat mass were analysed through bioelectrical impedance using a Tanita BC-418MA (Tanita Corporation, Tokyo, Japan) which uses a three-compartment model of body composition analysis. The International physical activity questionnaire (IPAQ) (Craig et al., 2003) assessed habitual physical activity levels (Table 1) and are reported in accordance with the IPAQ website (www.ipaq.ki.se). The present study population were classified as moderately-highly active. Finally, a 7-day food diary was completed over consecutive days. The front page contained instructions, to ensure details of preparation and portion sizes of all foods and beverages were reported. MyNetDiary Pro (iPhone App Version 5.45) calculated average daily calories (Kcal), protein (g), carbohydrate (g) and fat (g) (Table 1).

Functional performance assessments

A warm-up consisting of five minutes self-selected pace cycling and five dynamic stretches was completed before all assessments and exercise sessions. The 30-sec chair stand, arm curl, 6-min walk, chair sit-&-reach, back scratch and 8-ft up-&-go assessments were administered in accordance with the senior fitness test (Rikli & Jones, 1999) and balance tests with the short physical performance battery (SPPB) (Guralnik et al., 1994). Grip-strength was measured using a digital strain-gauge dynamometer (Takei TKK 5401, Takei Scientific Instruments, Tokyo, Japan) using instructions from the Groningen fitness test for the elderly (Lemmink et al., 2001). The least fatiguing assessments were performed first, and assessments that required more skilful movements were performed before more fatiguing assessments (Hoffman, 2012). The techniques and procedures for each test were thoroughly explained and demonstrated. Participants then completed a familiarisation attempt, followed by two experimental attempts, with the best performance recorded. To avoid excessive fatigue, the 6-min walk, 30-sec chair stand and arm curl tests were performed once. The time of day that participants completed baseline testing was repeated post-intervention, to reduce variation in the physical and performance tests due to circadian variation.

One-repetition maximum assessments

Participants were familiarised to the correct techniques for all resistance exercises (Table 2) using Cybex exercise equipment (Cybex, Medway, MA, USA) to minimise the learning effect. Familiarisation was suspended when technique had been mastered and the exercises were being performed safely. On the same day, estimations of 1-RM were made for each exercise, using load lifted and number of repetitions (Brzycki, 1993) (Table 2). For each exercise, participants performed repetitions with a load they felt was challenging but manageable. With 3-mins rest between efforts, resistance was progressively increased until momentary failure occurred within 10 repetitions, in accordance with recommendations (Brzycki, 1993). All estimations of 1-RM were achieved by all participants in no more than four attempts, within a range of 2-10 repetitions for all conditions. Supplementary Figure 2 displays a timeline of all baseline and post-intervention assessments and their sequence.

Resistance exercise protocols

Both the HVLL1 and HVLL2 conditions performed 3 sets of 14 repetitions at 40% predicted 1-RM. The concentric phase was performed “as fast as possible” followed by a 3-sec eccentric phase. Both LVHL1 and LVHL2 conditions performed 3 sets of 7 repetitions at 80% predicted 1-RM. The concentric phase was performed over 2-secs with a 3-sec eccentric phase. A command and metronome based protocol was used to differentiate between high and low velocities (Richardson et al., 2018). All sessions had 90-secs recovery between sets, 3-mins between exercises and were completed at the same time, on the same days weekly where possible. Two sessions were separated by a minimum of 48 hours. A total of 10 sessions were completed by once-weekly conditions and 20 by twice-weekly conditions. Therefore, the twice-weekly conditions performed double the training volume. Volume was not matched between conditions, as performing shorter sessions twice-weekly is less time efficient, and condensing two training sessions into one, creates highly physically demanding protocols, possibly discouraging some older adults. Meanwhile, CON continued habitual activity and made no efforts to change daily habits. To ensure all scheduled sessions were completed, the intervention period was extended if sessions were missed, resulting in a maximum duration of 10 weeks and 6 days.

Progression of Programmes

Rating of perceived exertion (RPE) (Borg, 1982) was recorded (6-20) immediately following each session. When a session was rated 10/20 on the Borg scale (too light/easy) (Levinger et al., 2017), exercises highlighted as "too easy" were increased in resistance by 5-10%. It was not disclosed that rating sessions 10/20 would result in increased resistance, to avoid deliberate manipulation by participants. This method allows participants some control over progression of intensity, which may be important for enhancing exercise pleasure and adherence (Lind et al., 2008). One LVHL2 participant rated their 20th session RPE 10. Four HVLL1 participants rated sessions as RPE 10 in week 8 (*n*=2) and 9 (*n*=2), and two HVLL2 participants in weeks 4 and 7, there were zero ratings of RPE 10 in LVHL1.

Adverse events

Prior to each session, a self-report adverse events form was completed, detailing adverse events following the previous session. Serious adverse events were defined as: deaths, prolonged hospital visits, significant incapacity or substantial disruptions in performing everyday tasks and minor adverse events as any event causing minor discomfort or inconvenience (Goodrich et al., 2007).

Sample size

Based on ANCOVA, reported effect sizes from Liu and Latham (2009) revealed a sample size of 18 and 22 in each group is necessary to detect changes in strength and functional performance, ensuring, 1–β=0.80 for an alpha level of 0.05 (Walker et al., 2017). However, Taaffe et al. (1999) suggest that 11 per group is sufficient to detect strength differences and Seynnes et al. (2004) suggest 18 per group for functional performance differences in older adults. Therefore, despite great effort to recruit more participants, our sample size is low. To ameliorate this, ancillary analyses were conducted to strengthen our conclusions.

Statistical analysis

All data were analysed using IBM SPSS Statistics, Version 24.0 (Armonk, NY: IBM Corp) and descriptive statistics presented as mean±SD, and 95% confidence intervals (95%CI). One-way analysis of variance

(ANOVA) compared baseline differences between conditions, including IPAQ responses and daily macronutrients. Analysis of covariance (ANCOVA), analysed between-condition differences, using baseline data as a covariate. Within-condition changes were analysed with Bonferroni corrected paired t-tests. Ancillary ANCOVA analyses were performed to compare the impact of movement velocity only [HVLL (*n*=20) vs. LVHL (*n*=20) vs. CON (*n*=10)] or frequency of exercise only [Once (*n*=20) vs. twice weekly (*n*=20) vs. CON (*n*=10)]. These data are available as online supplementary material and are only reported when significant. All Significance tests were two-tailed with an alpha level of 0.05 required for significance. All *p*-values are reported as exact values unless $p<0.001$. Partial eta squared (η_p^2) was used to quantify the meaningfulness of any differences, and defined as trivial (<0.1), small (0.1-0.29), moderate (0.3-0.49) or large (≥0.5) (Hopkins et al., 2009). Hedges' *g* effect size estimates were selected as they allow correction for smaller sample sizes, and were calculated using the adjusted means and pooled SD. The interpretation of Hedges' *g* is similar to Cohens *d* e.g. small (0.2-0.49), moderate (0.5-0.79), and large (≥0.8).

Results

Baseline differences

There were no significant baseline differences between conditions in any of the physical or physiological characteristics, IPAQ responses or daily macronutrients. However, 1-RM's for HVLL2 were greater than CON for leg extension (p=0.027;95%CI:1.4,37.1) and greater than LVHL1 for calf raise (p=0.017;95%CI:4.9,79.1).

Primary Outcomes

Balance assessments

All participants achieved maximum scores in all three SPPB balance assessments, at baseline and post-intervention.

Flexibility assessments

There were no within-condition changes for any condition in any flexibility test. Furthermore, there were no significant differences between conditions for both right ($F_{(4,44)}$=0.800; p=0.535; η_p^2=0.07) and left legs ($F_{(4,44)}$=0.427; p=0.788; η_p^2=0.04; Table 3) and back scratch right ($F_{(4,44)}$=0.537; p=0.683; η_p^2=0.05) and left arms ($F_{(4,44)}$=0.348; p=0.844; η_p^2=0.03; Table 3).

8-Ft Up-&-Go

Within-condition, LVHL1 reduced their time by 7% (p=0.010;95%CI: -0.69,-0.12; g=0.60) and HVLL2 by 8% (p=0.002;95%CI:-0.62,-0.20; g=0.41). There were no significant differences between conditions ($F_{(4,44)}$=2.183; p=0.087; η_p^2 =0.17; Table 3).

Chair Stands

Within-condition, HVLL1 increased the number of completed chair stands by 13% (p=0.012;95%CI: 0.48,2.92; g=0.39), LVHL1 by 15% (p=0.012;95%CI: 0.48,2.92; g=1.46), HVLL2 by 10% (p=0.048;95%CI: 0.02,2.98; g=0.35) and LVHL2 by 20% (p=0.023; 95%CI: 0.46,4.94; g=0.76) but only LVHL2 improved performance compared to CON (p=0.035;95%CI: 0.13,5.95; g=0.89; Table 3).

Arm Curls

Within-condition, HVLL1 increased the number of completed arm curls by 25% (p=0.029;95%CI:0.47,6.73; g=0.68), HVLL2 by 15% (p=0.026;95%CI: 0.42,5.18; g=0.41) and LVHL2 by 43% (p=0.002; 95%CI: 2.86,9.34; g=1.54). ANCOVA revealed LVHL2 improved performance compared to LVHL1 (p=0.020;95%CI: 0.57,10.82; g=1.51) and CON (p=0.011; 95%CI: 0.95,11.19; g=1.65; Table 3).

Grip-Strength Dominant Hand

There were no significant within or between-condition changes ($F_{(4,44)}$=1.989; p=0.113; η_p^2 =0.15;Table 3).

Grip-Strength Non-Dominant Hand

Within-condition, LVHL2 increased grip-strength by 10% (p=0.003; 95%CI: 1.1,4.1;g=0.23), and only LVHL2 improved grip-strength compared to CON (p=0.015; 95%CI:0.5,7.1;g=0.34; Table 3).

6-Min Walk

Within-condition, LVHL1 increased distance covered in the 6-min walk by 8% (p=0.007; 95%CI:15.03,70.57; g=0.55), HVLL2 by 7% (p=0.002;95%CI: 21.0,64.9; g=0.51) and LVHL2 by 7% (p=0.009;95%CI: 12.8,68.4; g=0.39). There were no significant differences between conditions ($F_{(4,44)}$=1.811; p=0.144; η_p^2 =0.14;Table 3).

Secondary Outcomes

Leg press

Within-condition, LVHL1 increased strength by 20% (p=0.002;95%CI: 10.1,31.4; g=0.65) and LVHL2 by 25% (p=0.003;95%CI: 12.7,44.0; g=0.77) but only LVHL2 increased strength compared to CON (p=0.039;95%CI: 0.9,58.0; g=0.71; Table 2).

Calf Raise

Within-condition, HVLL1 increased strength by 17% (p=0.015; 95%CI: 4.7,34.0; g=0.73), LVHL1 by 30% (p<0.001;95%CI: 19.9,38.6; g=0.88) and LVHL2 by 35% (p<0.001;95%CI: 31.4,50.8; g=1.50). ANCOVA revealed LVHL2 increased strength compared to HVLL2 (p=0.009;95%CI: 5.3,55.8; g=1.00) and CON (p=0.001;95%CI: 10.1,59.1; g=1.05; Table 2).

Leg extension

Within-condition, LVHL1 increased strength by 25% (p=0.002; 95%CI: 4.9, 16.2; g=0.68), HVLL2 by 9% (p=0.022; 95%CI: 0.9,9.0; g=0.23) and LVHL2 by 40% (p<0.001; 95%CI: 11.9,22.4; g=1.29). ANCOVA revealed LVHL2 improved strength compared to HVLL1 (p=0.002; 95%CI: 3.5,22.7; g=1.02), HVLL2 (p=0.013;95%CI: 1.6,21.7; g=0.65). and CON (p=0.003; 95%CI: 3.2,22.5; g=0.98; Table 2).

Leg curl

Within-condition, LVHL1 increased strength by 21% (p=0.001; 95%CI: 4.3,11.3; g=0.51), HVLL2 by 10% (p=0.020; 95%CI: 1.0,8.7; g=0.25) and LVHL2 by 28% (p<0.001; 95%CI: 8.1,14.8; g=0.87) but there were no significant differences between conditions ($F_{(4,44)}$=1.883; p=0.130; η_p^2 =0.15; Table 2).

Seated row

Within-condition, HVLL1 increased strength by 7% (p=0.044; 95%CI: 0.1,7.6; g=0.28), LVHL1 by 14% (p=0.005; 95%CI: 2.7,11.3; g=0.43) and HVLL2 by 11% (p=0.039; 95%CI: 0.4,12.8; g=0.28) and LVHL2 by 27% (p<0.001; 95%CI: 9.8,17.9; g=0.81). ANCOVA revealed LVHL1 (p=0.022; 95%CI: 0.8,17.2; g=0.52), HVLL2 (p=0.040; 95%CI: 0.2,16.7; g=0.40) LVHL2 (p<0.001; 95%CI: 7.7,24.0; g=0.89) all increased strength compared to CON (Table 2).

Chest press

Within-condition, LVHL1 increased strength by 18% (p=0.001; 95%CI: 3.3,8.2; g=0.27), HVLL2 by 12% (p=0.016; 95%CI: 1.2,9.4; g=0.25) and LVHL2 by 24% (p<0.001; 95%CI: 5.6,13.2; g=0.43). ANCOVA revealed LVHL1 (p=0.027; 95%CI: 0.5,13.9; g=0.36), HVLL2 (p=0.047; 95%CI:0.1,13.5; g=0.33) and LVHL2 (p<0.001; 95%CI: 4.2,17.5; g=0.49) increased strength compared to CON (Table 2).

Tricep Extension

Within-condition, HVLL1 increased strength by 18% (p=0.018; 95%CI: 1.0,8.1; g=0.49), LVHL1 by 24% (p=0.001; 95%CI: 3.0,8.1; g=0.44), HVLL2 by 16% (p=0.001; 95%CI: 2.4,7.2; g=0.30) and LVHL2 by 33% (p<0.001; 95%CI: 4.8,11.7; g=0.70). But only LVHL2 increased strength compared to CON (p=0.011; 95%CI: 1.0,12.2; g=0.50; Table 2).

Bicep curl

Within-condition, LVHL1 increased strength by 25% (p=0.001; 95%CI: 2.7,7.1; g=0.47), HVLL2 by 12% (p=0.003; 95%CI: 1.3,4.9; g=0.25) and LVHL2 by 45% (p<0.001; 95%CI: 5.3,12.5; g=0.72). ANCOVA revealed LVHL2 increased strength compared to HVLL1 (p=0.010; 95%CI: 1.0,11.2; g=0.52), HVLL2 (p=0.028; 95%CI: 0.4,10.7; g=0.43) and CON (p=0.002; 95%CI:1.8,12.0; g=0.53; Table 2).

Physical Assessments

There were no significant differences between conditions for BMI ($F_{(4,44)}$=2.111; p=0.096; η_p^2 =0.16; Table 4) or body mass ($F_{(4,44)}$=2.537; p=0.053; η_p^2 =0.19; Table 4). However, within-condition, both BMI (p=0.047; 95%CI: -0.7,-0.0; g=0.09) and body mass (p=0.037; 95%CI: -2.0,-0.1; g=0.07) decreased significantly in HVLL2. Furthermore, there were no significant differences between conditions for body fat percentage ($F_{(4,44)}$=2.290; p=0.075; η_p^2 =0.17; Table 4) or fat mass ($F_{(4,44)}$=1.957; p=0.118; η_p^2 =0.15; Table 4). Within-condition analyses revealed that both body fat percentage (p=0.002; 95%CI: 0.7,2.2; g=0.23) and fat mass (p=0.001; 95%CI: 0.7,1.9; g=0.24) increased in CON. Finally, there were significant differences between conditions in FFM ($F_{(4,44)}$=2.909; p=0.032; η_p^2 =0.21; Table 4). Increases in FFM were significantly greater in LVHL1 compared to HVLL2 (p=0.040; 95%CI: 0.04,3.11; g=0.16) as HVLL2 experienced losses of FFM (p=0.009; 95%CI: -1.95,-0.37; g=0.10).

Adverse Events

One HVLL2 participant withdrew with knee pain (causation unclear), and one HVLL1 participant with an abdominal hernia in week 2 (causation unclear). One LVHL2 participant withdrew in week 1 citing “lack of time”, and a CON participant withdrew with Ramsay Hunt syndrome. An injury occurred (unassociated with study) in LVHL1 causing one missed session. Minor adverse events are reported as number of participants affected (p) and number of reports (n). There were incidences of mild joint discomfort: HVLL1 (p=3:n=5), LVHL1(p=2:n=3) HVLL2 (p=3:n=3) LVHL2 (p=2:n=3) and muscle soreness: HVLL1 (p=3:n=8), LVHL1 (p=5:n=13) HVLL2 (p=3:n=3) LVHL2 (p=4:n=12), that did not affect participation.

Discussion

We sought to investigate the impact that HVLL and LVHL performed once or twice-weekly, have on indices of functional performance, maximal strength and body composition. The main finding was that LVHL2 elicited the greatest magnitudes of improvements in more tests of strength and functional performance than any other condition, compared to CON. However, within-condition analyses revealed that HVLL and LVHL performed once or twice-weekly improved some aspects of strength and functional performance. Supported by our ancillary analyses, hypothesis 1 must be rejected as there were greater benefits to performing volume-load matched LVHL compared to HVLL and hypothesis 2 is confirmed following more/greater benefits in the twice-weekly compared to once-weekly conditions.

Aside from flexibility, which was generally poor, participants exhibited sufficient pre-existing levels of functional fitness by meeting or exceeding normal range values (Rikli & Jones, 1999) at baseline. Although only LVHL2 significantly improved functional performance compared to CON in the present study, ancillary analyses revealed HVLL enhanced both arm curl and 8-ft-up-&-go performance compared to CON. Whereas, the LVHL conditions enhanced chair stands and grip-strength performance compared to CON. It is also important to highlight that within-condition changes revealed that HVLL1 improved chair stand and arm curl performance, and LVHL1 improved 8-ft-up-&-go, chair stand and 6-min walk performance compared to baseline. Therefore, the present study revealed some benefits to once-weekly resistance exercise in moderately-highly active, older adults, in as little as ~10 hours over 10-weeks with little progression of intensity.

Maximal strength increased in all exercise conditions, which over short interventions, are commonly attributed to neuromuscular adaptations (Barbalho et al., 2017). The greatest magnitudes of strength improvements were observed in LVHL2, with 7/8 exercises significantly improving compared to CON, compared to 2/8 in both HVLL2 and LVHL1. We speculate that the increased loading (80% 1-RM), in the LVHL conditions meant participants exercised at closer proximity to momentary failure, creating a greater stimulus for strength gains (Gentil et al., 2017). Indeed, the LVHL conditions produced failure on multiple exercises in the first 4-6 weeks, whereas the HVLL conditions did not cause failure on any exercise, except the bicep curl. As low intensity resistance exercise needs to performed to failure to gain the same strength gains as high-intensity resistance exercise (Nobrega & Libardi, 2016), it may explain why HVLL did not illustrate the same magnitudes of strength increases as LVHL. Furthermore, the LVHL conditions may have experienced greater increases in strength than HVLL, as maximum strength testing was more similar to the exercise performed by the LVHL conditions (Buckner et al., 2017).

The present study appears to contradict previous studies, where power training has produced similar improvements in muscular strength (Nogueira et al., 2009), and greater improvements in functional performance (Bottaro et al., 2007) compared to strength training. These differences may be explained by the loading used, both studies used 60% 1-RM for both strength and power training, meaning these protocols were better matched for intensity of effort compared to the present study. Furthermore, many power training studies that have observed greater functional outcomes compared with strength training, have used greater percentages of 1-RM than the present study (Byrne et al., 2016). Our findings suggest that LVHL is more beneficial to strength and functional performance in older adults when exercise is volume-load matched against HVLL, which may suggest that the intensity of resistance exercise is more important than its movement velocity.

There appeared to be clear advantages of performing these protocols with greater weekly volume, likely through greater neuromuscular adaptations (Cadore et al., 2018). Ancillary analyses revealed that twice-weekly conditions improved chair stands, arm curls, 8-Ft Up-&-Go, grip strength and maximal strength in 6/8 exercises significantly compared to CON. Whereas, once-weekly conditions only improved strength for the chest press and seated row compared to CON. These findings are in contrast with those of Turpela et al. (2017) who observed no additional benefits of higher training frequency for improvements in functional capacity. The differences in findings may be explained as Turpela et al. (2017) employed at least one concentric set to failure meaning that the intensity of effort was likely greater than in the present study.

Body mass and BMI decreased in HVLL2 beneficially, as BMI classifications indicated they were overweight. However, FFM also decreased in HVLL2, possibly due to low mean protein intake (0.78g/kg/day), which was significantly lower than the 1–1.3g/kg/day recommended for older adults while resistance training for attenuating age-related losses in muscle mass and improving functional performance (Nowson & O'Connell, 2015). Similar to the present study, inadequate protein consumption during an exercise intervention, has demonstrated both losses in body mass and lean body mass (Bopp et al., 2008). As protein requirements are higher for exercising older adults (Bauer et al., 2013), low protein intake combined with increased exercise may have exacerbated losses of FFM.

Limitations

Both functional and 1-RM assessments were conducted on the same day, meaning some assessments may have been affected by fatigue. To attenuate this, all assessments were performed in the same order with appropriate rest times. Secondly, the same researcher conducted the baseline and post-intervention assessment sessions and all sessions in the 10-week programme, meaning they were not blinded to condition assignment. Potential bias was counteracted by providing identical assessment procedures and motivation to all participants (Miszko et al., 2003). In addition to testing maximal strength, assessing muscle power would have been useful to observe and compare training specificity effects. We did not attempt to match the number of repetitions used by participants to predict their 1-RM at baseline and post-intervention. Therefore, given the error in the prediction equation, this may have affected the ability to distinguish between exercise conditions. However, the Brzycki equation has previously produced valid estimations of 1-RM on multiple machine based exercises in older adults (Knutzen et al., 1999). Lastly, our sample size was small, possibly increasing the risk of type 2 errors. Therefore, ancillary analyses were conducted to support our conclusions.

Conclusion

The present study indicates that 10-week programmes of LVHL, performed twice-weekly are most beneficial for already moderately-highly active older adults in improving strength and functional performance. We speculate that the greater intensity of effort required in the LVHL conditions compared to HVLL, provided participants with a greater stimulus to facilitate these improvements. Our ancillary analyses revealed that LVHL was more beneficial for strength and functional performance than HVLL, and twice-weekly was more beneficial than once-weekly. Despite this, within-condition changes indicated that all conditions improved some aspects of maximal strength and functional performance from baseline.

Practical Recommendations

Our volume-load matched protocols, suggest that the intensity of effort resistance exercise is performed at, may be more important for enhancement of strength and functional performance than movement velocity in older adults. Furthermore, we observed superior benefits from performing these resistance exercise protocols with greater weekly volume (twice-weekly vs. once-weekly). Therefore, whether utilising HVLL or LVHL, exercise professionals should ensure that programmes contain sufficient weekly volume and intensity of effort to maximise functional performance and strength gains in older adults. In agreement with Fisher et al. (2017), exercise professionals may elect to begin with a minimal dose/intensity of supervised resistance exercise and progress programmes through manipulation of volume and/or load when participants show adequate progression.

References

Barbalho, M. S. M., Gentil, P., Izquierdo, M., Fisher, J., Steele, J., & Raiol, R. A. (2017). There are no no-responders to low or high resistance training volumes among older women. *Experimental gerontology, 99*, 18-26. doi:10.1016/j.exger.2017.09.003

Barber, L., Scicchitano, B. M., & Musaro, A. (2015). Molecular and Cellular Mechanisms of Muscle Aging and Sarcopenia and Effects of Electrical Stimulation in Seniors. *European journal of translational myology*, *25*(4), 231-236. doi:10.4081/ejtm.2015.5227

Bauer, J., Biolo, G., Cederholm, T., Cesari, M., Cruz-Jentoft, A. J., Morley, J. E., . . . Boirie, Y. (2013). Evidence-based recommendations for optimal dietary protein intake in older people: a position paper from the PROT-AGE Study Group. *Journal of the American Medical Directors Association, 14*(8), 542-559. doi:10.1016/j.jamda.2013.05.021

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.

Beltran Valls, M. R., Dimauro, I., Brunelli, A., Tranchita, E., Ciminelli, E., Caserotti, P., . . . Caporossi, D. (2014). Explosive type of moderate-resistance training induces functional, cardiovascular, and molecular adaptations in the elderly. *Age (Dordrecht, Netherlands), 36*(2), 759-772. doi:10.1007/s11357-013-9584-1

Bopp, M. J., Houston, D. K., Lenchik, L., Easter, L., Kritchevsky, S. B., & Nicklas, B. J. (2008). Lean mass loss is associated with low protein intake during dietary-induced weight loss in postmenopausal women. *Journal of the American Dietetic Association, 108*(7), 1216-1220. doi:10.1016/j.jada.2008.04.017

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and science in sports and exercise, 14*(5), 377-381.

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. doi:10.1007/s00421-006-0343-1

Brzycki, M. (1993). Strength testing—predicting a one-rep max from reps-to-fatigue. *Journal of Physical Education, Recreation & Dance, 64*(1), 88-90.

Buckner, S. L., Jessee, M. B., Mattocks, K. T., Mouser, J. G., Counts, B. R., Dankel, S. J., & Loenneke, J. P. (2017). Determining Strength: A Case for Multiple Methods of Measurement. *Sports medicine (Auckland, N.Z.), 47*(2), 193-195. doi:10.1007/s40279-016-0580-3

Byrne, C., Faure, C., Keene, D. J., & Lamb, S. E. (2016). Ageing, Muscle Power and Physical Function: A Systematic Review and Implications for Pragmatic Training Interventions. *Sports medicine (Auckland, N.Z.), 46*(9), 1311-1332. doi:10.1007/s40279-016-0489-x

Cadore, E. L., Pinto, R. S., Bottaro, M., & Izquierdo, M. (2014). Strength and endurance training prescription in healthy and frail elderly. *Aging and disease, 5*(3), 183-195. doi:10.14336/ad.2014.0500183

Cadore, E. L., Pinto, R. S., Reischak-Oliveira, A., & Izquierdo, M. (2018). Explosive type of contractions should not be avoided during resistance training in elderly. *Experimental gerontology, 102*, 81-83. doi:10.1016/j.exger.2017.12.003

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., . . . Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and science in sports and exercise, 35*(8), 1381-1395. doi:10.1249/01.mss.0000078924.61453.fb

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. *The journals of gerontology. Series A, Biological sciences and medical sciences, 60*(5), 638-647.

Doherty, T. J. (2003). Invited review: Aging and sarcopenia. *Journal of applied physiology (Bethesda, Md. : 1985), 95*(4), 1717-1727. doi:10.1152/japplphysiol.00347.2003

Fisher, J. P., Steele, J., Gentil, P., Giessing, J., & Westcott, W. L. (2017). A minimal dose approach to resistance training for the older adult; the prophylactic for aging. *Experimental gerontology, 99*, 80-86. doi:10.1016/j.exger.2017.09.012

Foley, A., Hillier, S., & Barnard, R. (2011). Effectiveness of once-weekly gym-based exercise programmes for older adults post discharge from day rehabilitation: a randomised controlled trial. *British journal of sports medicine, 45*(12), 978-986. doi:10.1136/bjsm.2009.063966

Gentil, P., Steele, J., & Fisher, J. (2017). Why intensity is not a bad word - Benefits and practical aspects of high effort resistance training to the older. *Clinical nutrition (Edinburgh, Scotland), 36*(5), 1454-1455. doi:10.1016/j.clnu.2017.05.024

Goodrich, D. E., Larkin, A. R., Lowery, J. C., Holleman, R. G., & Richardson, C. R. (2007). Adverse events among high-risk participants in a home-based walking study: a descriptive study. *The international journal of behavioral nutrition and physical activity, 4*, 20. doi:10.1186/1479-5868-4-20

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., . . . Wallace, R. B. (1994). A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *Journal of gerontology, 49*(2), M85-94.

Hoffman, J. (2012). *NSCA's Guide to Program Design* (J. Hoffman Ed.). USA: Human Kinetics

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and science in sports and exercise, 41*(1), 3-13. doi:10.1249/MSS.0b013e31818cb278

Knutzen, K. M., Brilla, L. R., & Caine, D. (1999). Validity of 1RM Prediction Equations for Older Adults. *The Journal of Strength and Conditioning Research, 13*(3), 242-246.

Lemmink, K. A., Han, K., de Greef, M. H., Rispens, P., & Stevens, M. (2001). Reliability of the Groningen fitness test for the elderly. *Journal of aging and physical activity, 9*(2), 194-212.

Levinger, P., Dunn, J., Bifera, N., Butson, M., Elias, G., & Hill, K. D. (2017). High-speed resistance training and balance training for people with knee osteoarthritis to reduce falls risk: study protocol for a pilot randomized controlled trial. *Trials, 18*(1), 384. doi:10.1186/s13063-017-2129-7

Lind, E., Ekkekakis, P., & Vazou, S. (2008). The affective impact of exercise intensity that slightly exceeds the preferred level: 'pain' for no additional 'gain'. *Journal of health psychology, 13*(4), 464-468. doi:10.1177/1359105308088517

Liu, C. J., & Latham, N. K. (2009). Progressive resistance strength training for improving physical function in older adults. *The Cochrane database of systematic reviews*(3), Cd002759. doi:10.1002/14651858.CD002759.pub2

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

Nobrega, S. R., & Libardi, C. A. (2016). Is Resistance Training to Muscular Failure Necessary? *Frontiers in physiology, 7*, 10. doi:10.3389/fphys.2016.00010

Nogueira, W., Gentil, P., Mello, S. N., Oliveira, R. J., Bezerra, A. J., & Bottaro, M. (2009). Effects of power training on muscle thickness of older men. *International journal of sports medicine, 30*(3), 200-204. doi:10.1055/s-0028-1104584

Nowson, C., & O'Connell, S. (2015). Protein Requirements and Recommendations for Older People: A Review. *Nutrients, 7*(8), 6874-6899. doi:10.3390/nu7085311

Raj, I. S., Bird, S. R., & Shield, A. J. (2010). Aging and the force-velocity relationship of muscles. *Experimental gerontology, 45*(2), 81-90. doi:10.1016/j.exger.2009.10.013

Ramirez-Campillo, R., Martinez, C., de La Fuente, C. I., Cadore, E. L., Marques, M. C., Nakamura, F. Y., . . . Izquierdo, M. (2017). High-Speed Resistance Training in Older Women: The Role of Supervision. *Journal of aging and physical activity, 25*(1), 1-9. doi:10.1123/japa.2015-0122

Richardson, D. L., Duncan, M. J., Jimenez, A., Jones, V. M., Juris, P. M., & Clarke, N. D. (2018). Movement velocity during high- and low-velocity resistance exercise protocols in older adults. *Experimental gerontology, 107*, 140-147. doi:https://doi.org/10.1016/j.exger.2017.09.020

Rikli, R. E., & Jones, C. J. (1999). Development and validation of a functional fitness test for community-residing older adults. *Journal of aging and physical activity, 7*(2), 129-161.

Seynnes, O., Fiatarone Singh, M. A., Hue, O., Pras, P., Legros, P., & Bernard, P. L. (2004). Physiological and functional responses to low-moderate versus high-intensity progressive resistance training in frail elders. *The journals of gerontology. Series A, Biological sciences and medical sciences, 59*(5), 503-509.

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.

Turpela, M., Hakkinen, K., Haff, G. G., & Walker, S. (2017). Effects of different strength training frequencies on maximum strength, body composition and functional capacity in healthy older individuals. *Experimental gerontology, 98*, 13-21. doi:10.1016/j.exger.2017.08.013

Walker, S., Haff, G. G., Hakkinen, K., & Newton, R. U. (2017). Moderate-Load Muscular Endurance Strength Training Did Not Improve Peak Power or Functional Capacity in Older Men and Women. *Frontiers in physiology, 8*, 743. doi:10.3389/fphys.2017.00743

Table 1. Participant characteristics

	HVLL1 (*n* = 10; 5m, 5f)	LVHL1 (*n* = 10; 5m, 5f)	HVLL2 (*n* = 10; 5m, 5f)	LVHL2 (*n* = 10; 5m, 5f)	CON (*n* = 10; 5m, 5f)
Age (years)	66 ± 5	67 ± 4	67 ± 6	66 ± 6	65 ± 5
Age Range (years)	60 – 74	60 – 72	60 – 78	60 – 79	61 – 76
Height (cm)	168.7 ± 7.4	167.2 ± 11.1	173.3 ± 9.7	166.8 ± 8.9	170.4 ± 9.5
Body Mass (kg)	80.0 ± 16.9	76.3 ± 11.8	83.2 ± 13.5	73.0 ± 13.4	71.4 ± 12.7
BMI (kg/m^2)	28 ± 5	28 ± 5	28 ± 5	26 ± 4	24 ± 3
Physical Activity (MET-min/week)	2919 (1771 – 4345)	3264 (2064 – 4067)	3095 (2381 – 4487)	2355 (1074 – 4026)	1767 (984 – 3428)
Daily Sitting (min)	330 (255 – 368)	195 (165 – 285)	240 (180 – 263)	360 (255 – 465)	300 (240 – 360)
Medical Conditions	1 ± 2	1 ± 1	1 ± 1	1 ± 1	1 ± 1
Number of Medications	2 ± 3	1 ± 1	1 ± 1	2 ± 2	1 ± 1
Most Commonly Medicated Condition(s)	High Blood Pressure (3/10)	Acid Reflux (2/10)	High Blood Pressure (2/10)	High Blood Pressure (5/10) Acid Reflux (2/10)	High Blood Pressure (4/10)
Most Common medication(s)	Simvastatin Atorvastatin	Omeprazole	Amlodipine Ramipril	Simvastatin Valsartan Omeprazole	Amlodipine Atenolol Atorvastatin
Daily Macronutrients					
Carbohydrate (g)	237 ± 83	231 ± 74	233 ± 72	245 ± 74	233 ± 64
Protein (g)	72 ± 21	75 ± 24	65 ± 22	67 ± 24	65 ± 23
Fat (g)	75 ± 38	67 ± 33	69 ± 27	68 ± 22	58 ± 26
Calories (Kcal)	1974 ± 609	1840 ± 571	1875 ± 507	1903 ± 509	1734 ± 471

Note: Values are mean ± SD except for weekly activity and sitting which are the median and interquartile ranges; m = male f = female; BMI = Body mass index; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition

Table 2. Predicted 1-RM data (Brzycki 1993) for baseline and post-intervention

	HVLL1 (*n* = 10; 5m, 5f)			LVHL1 (*n* = 10; 5m, 5f)			HVLL2 (*n* = 10; 5m, 5f)			LVHL2 (*n* = 10; 5m, 5f)			CON (*n* = 10; 5m, 5f)		
	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES
Leg press (kg)															
Baseline	103 ± 23	86.1 – 119.0	–	104 ± 29	83.3 – 125.4	–	135 ± 39	107.0 – 162.9	–	114 ± 28	94.1 – 134.8	–	95 ± 39	67.6 – 123.0	–
Post-intervention	117 ± 29	96.6 – 138.0	0.59	125 ± 32*	102.3 – 147.9	0.65	150 ± 44	118.4 – 181.3	0.34	143 ± 41*#	113.5 – 172.2	0.77	95 ± 38	68.0 – 122.3	0.00
Calf Raise (kg)															
Baseline	116 ± 21	101.1 – 131.6	–	97 ± 31	74.7 – 119.5	–	139 ± 31	117.0 – 161.2	–	117 ± 26	97.8 – 135.3	–	107 ± 30	86.2 – 128.7	–
Post-intervention	136 ± 29*	114.8 – 156.5	0.73	126 ± 32*	103.2 – 149.5	0.88	148 ± 32	124.7 – 170.4	0.26	158 ± 26*#¥	138.8 – 176.5	1.50	115 ± 36	88.8 – 140.7	0.21
Leg Extension (kg)															
Baseline	41 ± 8	35.9 – 46.9	–	42 ± 14	31.3 – 52.0	–	55 ± 21	39.8 – 70.4	–	42 ± 10	35.4 – 49.5	–	36 ± 10	29.2 – 43.0	–
Post-intervention	45 ± 9	39.3 – 51.6	0.48	52 ± 15*	41.2 – 63.2	0.68	60 ± 19*	46.3 – 73.8	0.23	60 ± 15*#¥†	48.8 – 70.3	1.29	41 ± 14	30.6 – 50.6	0.36
Leg Curl (kg)															
Baseline	40 ± 12	31.0 – 48.8	–	37 ± 12	28.2 – 46.1	–	48 ± 17	35.8 – 60.2	–	41 ± 11	33.3 – 48.9	–	36 ± 10	29.4 – 43.5	–
Post-intervention	45 ± 6	40.5 – 49.5	0.49	45 ± 17*	33.1 – 56.8	0.51	53 ± 20*	38.6 – 67.1	0.25	53 ± 14*	42.4 – 62.6	0.87	40 ± 14	29.9 – 50.6	0.29
Seated Row (kg)															
Baseline	53 ± 14	43.3 – 62.6	–	51 ± 15	40.4 – 61.2	–	59 ± 21	43.9 – 73.5	–	51 ± 15	40.2 – 61.7	–	51 ± 19	37.8 – 64.5	–
Post-intervention	57 ± 13*	47.8 – 65.8	0.28	58 ± 17*#	45.7 – 70.0	0.43	65 ± 24*#	48.1 – 82.5	0.28	65 ± 18*#†	52.1 – 77.5	0.81	49 ± 16	37.5 – 60.9	-0.11
Chest Press (kg)															
Baseline	35 ± 14	25.2 – 45.5	–	33 ± 21	17.4 – 47.9	–	44 ± 21	29.6 –59.0	–	38 ± 19	25.0 – 51.9	–	37 ± 19	23.1 – 50.9	–
Post-intervention	39 ± 16	28.2 – 50.6	0.26	38 ± 20*#	24.3 – 52.5	0.27	50 ± 20*#	35.2 – 63.9	0.25	48 ± 23*#	31.5 – 64.2	0.43	36 ± 19	21.9 – 49.3	-0.07
Tricep Extension (kg)															
Baseline	25 ± 10	17.8 – 31.7	–	23 ± 12	14.0 – 31.6	–	30 ± 16	18.2 – 41.4	–	25 ± 10	18.0 – 32.1	–	23 ± 14	12.6 – 32.4	–
Post-intervention	29 ± 8*	23.7 – 34.8	0.49	28 ± 12*	19.9 – 36.9	0.44	35 ± 15*	24.0 – 45.3	0.30	33 ± 12*#	24.4 – 42.2	0.70	24 ± 13	15.1 – 33.6	0.13
Bicep Curl (kg)															
Baseline	20 ± 10	12.8 – 27.7	–	20 ± 10	12.5 – 26.6	–	26 ± 12	16.8 – 34.4	–	20 ± 10	12.5 – 27.3	–	19 ± 12	10.6 – 27.7	–
Post-intervention	23 ± 9	16.9 – 29.3	0.28	24 ± 10*	17.3 – 31.6	0.47	29 ± 11*	20.6 – 36.9	0.25	29 ± 13*#¥†	19.4 – 38.2	0.72	21 ± 12	12.6 – 29.8	0.16

Note: m = male f = female; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition; ES = Hedges' *g* within-condition effect size estimate
***** = Significantly different from baseline; † = Significantly greater than HVLL1; ¥ = Significantly greater than HVLL2; # = Significantly greater than CON

Table 3. Functional performance changes from baseline to post-intervention

	HVLL1 (*n* = 10; 5m, 5f)			LVHL1 (*n* = 10; 5m, 5f)			HVLL2 (*n* = 10; 5m, 5f)			LVHL2 (*n* = 10; 5m, 5f)			CON (*n* = 10; 5m, 5f)		
	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES
Chair Sit-&-Reach (cm) Right															
Baseline	-6 ± 14	-15.6 – 3.8	–	-18 ± 14	-28.3 – -8.5	–	-8 ± 9	-14.8 – -1.3	–	-9 ± 11	-17.1 – -1.8	–	-1 ± 11	-8.7 – 6.8	–
Post-intervention	-7 ± 15	-17.5 – 3.6	-0.07	-16 ± 12	-24.6 – -7.8	0.16	-5 ± 9	-11.1 – 1.7	0.35	-9 ± 14	-18.5 – 1.0	0.06	-4 ± 13	-12.9 – 5.5	-0.22
Chair Sit-&-Reach (cm) Left															
Baseline	-6 ± 12	-15.0 – 2.7	–	-17 ± 15	-27.8 – -7.0	–	-7 ± 11	-15.2 – 1.1	–	-10 ± 11	-17.6 – -1.8	–	-2 ± 12	-10.5 – 7.0	–
Post-intervention	-8 ± 14	-17.5 – 2.3	-0.11	-15 ± 13	-24.4 – -5.5	0.17	-5 ± 10	-12.1 – 2.4	0.20	-9 ± 13	-17.7 – 0.4	0.08	-1 ± 11	-9.2 – 6.5	0.03
Back Scratch (cm) Right															
Baseline	-9 ± 12	-17.9 – -0.3	–	-16 ± 10	-23.5 – -8.6	–	-12 ± 12	-20.8 – -3.3	–	-9 ± 10	-16.5 – -2.3	–	-7 ± 11	-14.2 – 0.8	–
Post-intervention	-12 ± 12	-20.4 – -3.0	-0.21	-14 ± 9	-20.9 – -8.0	0.16	-13 ± 12	-21.1 – -4.0	0.04	-10 ± 10	-17.4 – -2.8	-0.07	-8 ± 10	-14.7 – -1.1	-0.11
Back Scratch (cm) Left															
Baseline	-15 ± 13	-24.7 – -5.6	–	-18 ± 10	-25.6 – -11.2	–	-16 ± 14	-25.9 – -5.8	–	-12 ± 9	-18.1 – -5.9	–	-12 ± 10	-18.5 – -4.6	–
Post-intervention	-15 ± 12	-24.2 – -6.4	-0.01	-19 ± 11	-27.1 – -11.0	0.06	-18 ± 15	-28.4 – -6.8	0.12	-12 ± 9	-17.7 – -5.6	0.04	-13 ± 14	-23.5 – -3.0	-0.13
8-Ft Up-&-Go (s)															
Baseline	5.7 ± 1.4	4.72 – 6.66	–	6.0 ± 0.7	5.46 – 6.45	–	5.1 ± 1.1	4.30 – 5.80	–	5.6 ± 0.8	5.05 – 6.23	–	5.3 ± 0.6	4.86 – 5.71	–
Post-intervention	5.4 ± 1.4	4.43 – 6.46	0.17	5.6 ± 0.6*	5.12 – 5.98	0.60	4.6 ± 0.9*	4.01 – 5.27	0.41	5.4 ± 0.5	5.02 – 5.78	0.34	5.4 ± 0.7	4.86 – 5.92	-0.15
Chair Stands (no. of stands)															
Baseline	13 ± 5	9.4 – 16.0	–	11 ± 1	10.3 – 12.1	–	15 ± 4	12.0 – 17.6	–	14 ± 3	11.6 – 15.6	–	13 ± 2	11.7 – 15.1	–
Post-intervention	14 ± 4*	11.5 – 17.3	0.39	13 ± 1*	12.2 – 13.6	1.46	16 ± 4*	13.2 – 19.4	0.35	16 ± 4 *#	13.5 – 19.1	0.76	13 ± 2	11.4 – 14.8	-0.12
Arm Curls (repetitions)															
Baseline	14 ± 5	10.6 – 18.0	–	15 ± 2	13.2 – 16.6	–	19 ± 6	14.1 – 22.9	–	14 ± 3	11.9 – 16.5	–	15 ± 4	11.4 – 17.7	–
Post-intervention	18 ± 5*	14.3 – 21.5	0.68	15 ± 3	13.0 – 17.0	0.04	21 ± 7*	16.4 – 26.2	0.41	20 ± 4 *‡#	17.2 – 23.4	1.54	14 ± 3	12.6 – 16.2	-0.03
GS (kg) Dominant Hand															
Baseline	28 ± 9	21.5 – 34.6	–	24 ± 6	20.4 – 28.3	–	36 ± 12	27.4 – 44.5	–	28 ± 11	20.4 – 36.2	–	29 ± 11	21.6 – 37.0	–
Post-intervention	28 ± 6	23.0 – 32.5	-0.03	26 ± 6	21.6 – 30.4	0.26	36 ± 12	27.3 – 43.8	-0.03	30 ± 11	22.4 – 38.6	0.19	28 ± 12	19.2 – 36.2	-0.13
GS (kg) Non-Dominant Hand															
Baseline	27 ± 8	21.7 – 32.9	–	24 ± 6	19.7 – 28.6	–	33 ± 13	23.8 – 42.8	–	28 ± 11	19.6 – 35.7	–	27 ± 10	20.1 – 34.4	–
Post-intervention	27 ± 6	22.8 – 31.8	0.00	25 ± 6	20.9 – 29.6	0.16	34 ± 12	25.3 – 42.1	0.03	30 ± 11*#	22.3 – 38.3	0.23	26 ± 10	18.7 – 33.5	-0.10
6-Min Walk (m)															
Baseline	535 ± 100	464 – 607	–	514 ± 76	460 – 569	–	617 ± 79	561 – 673	–	554 ± 108	477 – 631	–	527 ± 92	462 – 593	–
Post-intervention	560 ± 112	481 – 640	0.23	557 ± 74*	504 – 610	0.55	660 ± 84*	600 – 720	0.51	595 ± 93*	528 – 661	0.39	542 ± 65	495 – 589	0.18

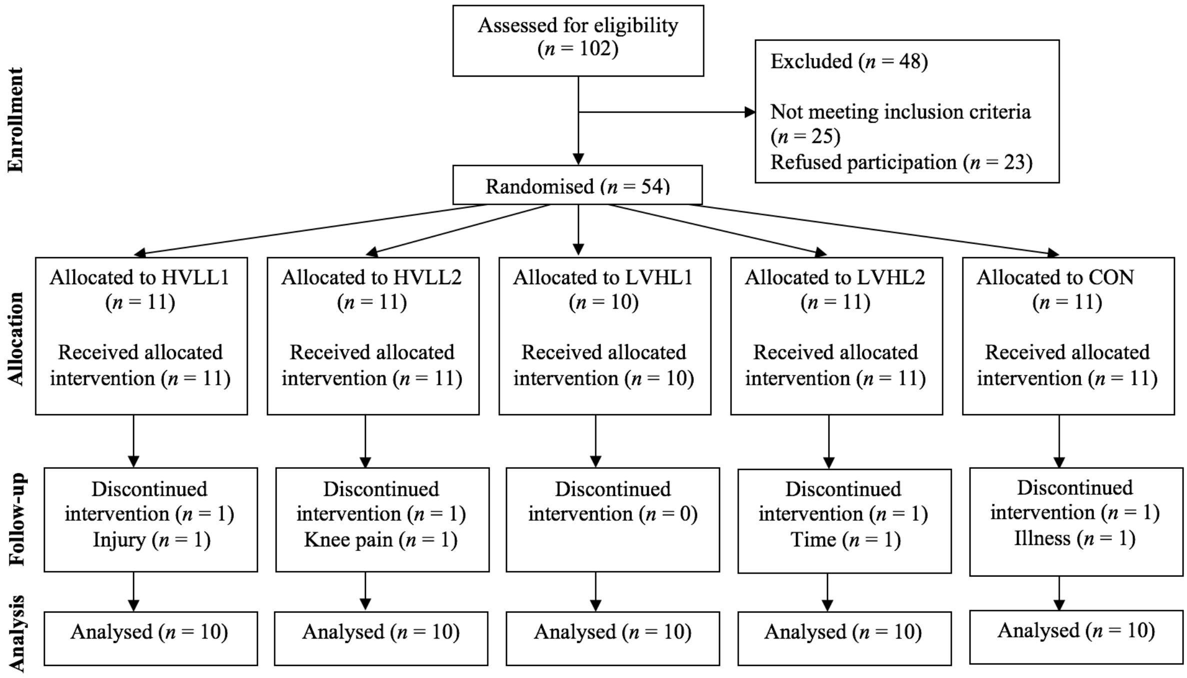
Note: m = male f = female; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition; GS = Grip-strength; ES = Hedges' *g* within-condition effect size estimate

***** = Significantly different from baseline; **‡** = Significantly greater than LVHL1; # = Significantly greater than CON

Table 4. Physical and physiological changes from baseline to post-intervention

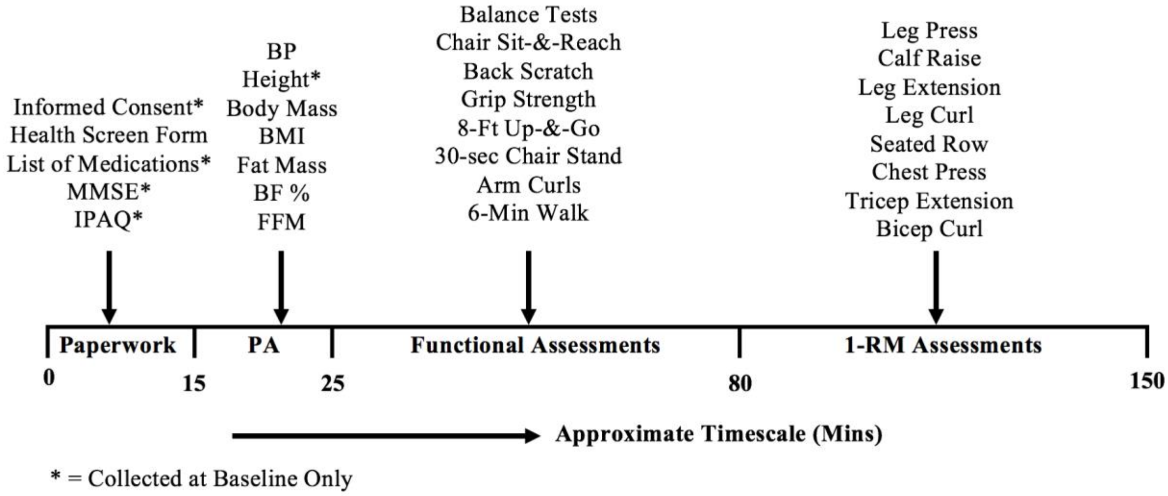
	HVLL1 (*n* = 10; 5m, 5f)			LVHL1 (*n* = 10; 5m, 5f)			HVLL2 (*n* = 10; 5m, 5f)			LVHL2 (*n* = 10; 5m, 5f)			CON (*n* = 10; 5m, 5f)		
	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES
BMI (kg/m^2)															
Baseline	28 ± 5	24.3 – 31.6	-	28 ± 5	23.9 – 31.0	-	28 ± 5	24.5 – 30.9	-	26 ± 4	23.1 – 29.4	-	24 ± 3	22.6 – 26.1	-
Post-intervention	28 ± 5	24.0 – 31.5	0.04	27 ± 5	24.1 – 30.8	0.00	27 ± 4*****	24.2 – 30.4	0.09	26 ± 4	23.2 – 29.4	0.00	25 ± 3	22.7 – 26.4	0.06
Body Mass (kg)															
Baseline	80.0 ± 16.9	67.9 – 92.1	-	76.3 ± 11.8	67.8 – 84.7	-	83.2 ± 13.5	73.5 – 92.8	-	73.0 ± 13.4	63.4 – 82.6	-	71.4 ± 12.7	62.3 – 80.5	-
Post-intervention	79.4 ± 17.6	66.8 – 92.0	0.03	76.3 ± 11.2	68.3 – 84.2	0.00	82.2 ± 13.5*****	72.5 – 91.8	0.07	73.1 ± 13.5	63.4 – 82.7	0.01	71.9 ± 12.6	63.0 – 80.9	0.04
BF (%)															
Baseline	30.9 ± 9.0	24.5 – 37.3	-	34.1 ± 8.6	28.0 – 40.2	-	31.2 ± 8.4	25.2 – 37.2	-	28.9 ± 11.2	20.9 – 36.9	-	27.5 ± 5.9	23.2 – 31.7	-
Post-intervention	30.2 ± 9.3	23.5 – 36.9	0.07	33.6 ± 8.2	27.7 – 39.4	0.06	31.7 ± 8.0	26.0 – 37.5	0.06	29.3 ± 11.6	21.0 – 37.6	0.04	28.9 ± 6.0*****	24.6 – 33.2	0.23
Fat Mass (kg)															
Baseline	25.0 ± 9.6	18.1 – 31.9	-	26.3 ± 8.9	19.9 – 32.7	-	26.1 ± 9.7	19.2 – 33.0	-	21.3 ± 9.1	14.8 – 27.8	-	19.5 ± 4.8	16.0 – 22.9	-
Post-intervention	24.5 ± 10.2	17.2 – 31.8	0.05	25.7 ± 8.1	19.9 – 31.5	0.06	26.2 ± 9.3	19.6 – 32.9	0.01	21.6 ± 9.2	15.0 – 28.2	0.03	20.7 ± 5.3*****	16.9 – 24.5	0.24
Fat Free Mass (kg)															
Baseline	55.0 ± 12.1	46.3 – 63.6	-	50.0 ± 9.0	43.5 – 56.5	-	57.1 ± 11.1	49.2 – 65.0	-	51.7 ± 11.7	43.3 – 60.0	-	52.0 ± 11.3	43.9 – 60.0	-
Post-intervention	54.9 ± 11.8	46.4 – 63.4	0.00	50.5 ± 9.2¥	43.9 – 57.1	0.05	55.9 ± 10.8*****	48.2 – 63.7	0.10	51.5 ± 12.2	42.7 – 60.2	0.02	51.2 ± 10.5	43.7 – 58.7	0.07

Note: m = male f = female; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition; BMI = Body mass index; BF% = Body fat percentage; ES = Hedges' *g* within-condition effect size estimate
***** = Significantly different from baseline; ¥ = Significantly greater than HVLL2



Supplementary Figure 1. CONSORT flow diagram of progress through phases of the study

Note: HVLL1 = High-velocity, Low-load once-weekly; LVHL1 = Low-velocity, High-load once-weekly; HVLL2 = High-velocity, Low-load twice-weekly; LVHL2 = Low-velocity, High-load twice-weekly; CON = Control Condition



Supplementary Figure 2: A schematic of the baseline and post-intervention assessments

Note: MMSE = Mini-Mental State Examination; IPAQ = International Physical Activity Questionnaire; BF% = Body Fat Percentage; FFM = Fat Free Mass; BP = Blood Pressure; PA = Physical Assessments; 1-RM = One-repetition maximum

Ancillary analysis of covariance (ANCOVA), reported for outcome measures only where significant differences were found.

Primary Outcomes

8-Ft Up-&-Go

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=3.214;p=0.049;η_p^2 =0.12) and between once and twice-weekly ($F_{(2,46)}$=3.243;p=0.048;η_p^2 =0.12). HVLL (p=0.050;95%CI: -0.8, 0.0; g=0.38) and twice-weekly conditions (p=0.048;95%CI: -0.8,0.0; g=0.52) reduced 8-Ft Up-&-Go times compared to CON.

Chair Stands

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=3.937;p=0.026;η_p^2 =0.15) and between once and twice-weekly ($F_{(2,46)}$=4.584;p=0.015;η_p^2 =0.17). LVHL (p=0.027; 95%CI: 0.2,4.5; g=0.75) and twice-weekly conditions (p=0.012;95%CI: 0.5, 4.7; g=0.70) improved chair stand performance compared to CON.

Arm Curls

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=3.175;p=0.050;η_p^2 =0.12) and between once and twice-weekly ($F_{(2,46)}$=7.047;p=0.002;η_p^2 =0.24). HVLL improved performance compared to CON (p=0.050;95%CI:-0.0,8.3;g=0.84) and twice-weekly conditions improved performance compared to both once-weekly (p=0.029;95%CI: 0.3, 6.6; g=0.68) and CON (p=0.003;95%CI: 1.6,9.3; g=1.09).

Grip-Strength Dominant Hand

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=3.932;p=0.027;η_p^2 =0.15). Only LVHL improved grip-strength compared to CON (p=0.030;95%CI: 0.3,6.3; g=0.32).

Grip-Strength Non-Dominant Hand

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=4.287;p=0.020;η_p^2 =0.16) and between once and twice-weekly ($F_{(2,46)}$=4.750;p=0.013;η_p^2 =0.17). LVHL

(p=0.018; 95%CI: 0.4,5.3; g=0.29) and twice-weekly conditions (p=0.012; 95%CI: 0.5,5.4; g=0.26) improved grip-strength compared to CON.

Secondary outcomes

Leg press

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=4.778; p=0.013; η_p^2 =0.17). LVHL increased strength significantly compared to CON (p=0.011; 95%CI: 4.9, 45.6; g=0.66). Lastly, there was a significant effect of frequency ($F_{(2,46)}$=3.953; p=0.026; η_p^2 =0.15). The twice-weekly conditions significantly increased leg press strength compared to CON (p=0.025; 95%CI: 2.4, 45.5; g=0.58).

Calf Raise

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=8.861; p=0.001; η_p^2 =0.28). LVHL increased strength significantly compared to HVLL (p=0.009; 95%CI: 4.0, 35.1; g=0.60) and CON (p=0.001; 95%CI: 9.7, 45.9; g=0.80). Lastly, there was a significant effect of frequency ($F_{(2,46)}$=3.565; p=0.036; η_p^2 =0.13). The twice-weekly conditions improved calf raise strength significantly compared to CON (p=0.037; 95%CI: 1.0, 42.0; g=0.66).

Leg extension

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=9.283; p<0.001; η_p^2 =0.29). LVHL increased strength significantly compared to HVLL (p=0.001; 95%CI: 3.2, 15.1; g=0.57) and CON (p=0.007; 95%CI: 2.2, 16.7; g=0.62).

Seated row

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=12.299; p<0.001; η_p^2 =0.35). Both HVLL (p=0.022; 95%CI: 0.8, 13.4; g=0.38) and LVHL (p<0.001; 95%CI: 6.1, 18.7; g=0.71) increased strength significantly compared to CON. LVHL also significantly increased strength compared to HVLL (p=0.043; 95%CI: 0.1, 10.5; g=0.29). Lastly, there was a significant effect of frequency ($F_{(2,46)}$=11.520; p<0.001; η_p^2 =0.33). Once (p=0.017; 95%CI:

1.1, 13.8; *g*=0.48) and twice-weekly conditions (*p*<0.001; 95%CI: 5.9, 18.6; *g*=0.62) significantly increased seated row strength compared to CON.

Chest press

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=10.470; *p*<0.001; η_p^2 =0.31). Both HVLL (*p*=0.010; 95%CI: 1.2, 11.0; *g*=0.31) and LVHL (*p*<0.001; 95%CI: 4.1, 13.9; *g*=0.43) increased strength significantly compared to CON. Lastly, there was a significant effect of frequency ($F_{(2,46)}$=9.860; *p*<0.001; η_p^2 =0.30). Both once (*p*=0.008; 95%CI: 1.4, 11.3; *g*=0.34) and twice-weekly conditions (*p*<0.001; 95%CI: 3.9, 13.8; *g*=0.42) increased chest press strength compared to CON.

Tricep Extension

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=4.957; *p*=0.011; η_p^2 =0.18). LVHL increased strength significantly compared to CON (*p*=0.009; 95%CI: 1.1, 9.2; *g*=0.41). Lastly, there was a significant effect of frequency ($F_{(2,46)}$=4.892; *p*=0.012; η_p^2 =0.18). Twice-weekly conditions significantly increased tricep extension strength compared to CON (*p*=0.009; 95%CI: 1.1, 9.3; *g*=0.38).

Bicep curl

There were significant differences between HVLL and LVHL ($F_{(2,46)}$=6.744; *p*=0.003; η_p^2 =0.23). LVHL increased strength significantly compared to HVLL (*p*=0.014; 95%CI: 0.6, 7.0; *g*=0.34) and CON (*p*=0.008; 95%CI: 1.0, 8.7; *g*=0.41). Lastly, there was a significant effect of frequency ($F_{(2,46)}$=3.599; *p*=0.035; η_p^2 =0.14), the twice-weekly conditions increased bicep curl strength significantly compared to CON (*p*=0.040; 95%CI: 0.1, 8.3; *g*=0.34).

Physical assessments

There were significant differences between HVLL and LVHL for both BMI ($F_{(2,46)}$=4.030; *p*=0.024; η_p^2 =0.15) and body mass ($F_{(2,46)}$=4.803; *p*=0.013; η_p^2 =0.17). Pairwise comparisons revealed HVLL significantly decreased both BMI (*p*=0.045; 95%CI: -0.8,-0.0; *g*=0.10) and body mass (*p*=0.017; 95%CI: -2.4,-0.2; *g*=0.09) compared to CON.

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