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Training load does not affect detraining's effect on muscle volume, muscle strength and functional capacity among older adults

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Abstract

Research underlines the potential of low-load resistance exercise in older adults. However, while the effects of detraining from high-load protocols have been established, it is not known whether gains from low-load training would be better/worse maintained. The current study evaluated the effects of 24 weeks of detraining that followed 12 weeks of high- and low-load resistance exercise in older adults. Fifty-six older adults (68.0 ± 5.0 years) were randomly assigned to leg press and leg extension training at either HIGH load (2 x 10-15 repetitions at 80% of one-repetition maximum (1-RM)), LOW load (1 x 80-100 repetitions at 20% of 1-RM), or LOW+ load (1 x 60 repetitions at 20% of 1-RM, immediately followed by 1 x 10-20 repetitions at 40% 1-RM). The main outcome measures included mid-thigh muscle volume, leg press 1-RM, leg extension isometric and isokinetic strength, and functional performance. Tests were performed at baseline, post-intervention and after 24 weeks of detraining. Results show no effect of load on preservation of muscle volume, which returned to baseline after detraining. Training-induced gains in functional capacity and isometric strength were maintained, independent of load. HIGH and LOW+ were more beneficial than LOW for long-lasting gains in training-specific 1-RM. To conclude, gains in muscle volume are reversed after 24 weeks of detraining, independent of load. This emphasises the need for long-term resistance exercise adherence. The magnitude of detraining in neuromuscular and functional adaptations were similar between groups. These findings underline the value of low-load resistance exercise in older age. Clinical Trial Registration NCT01707017.

Keywords sarcopenia; muscle hypertrophy; elderly; resistance exercise

Highlights

- Hypertrophy is reversed after 24 weeks of detraining, independent of training load.
- Prior load does not affect decline rates in muscle strength caused by detraining.
- Training-induced gains in functional capacity are maintained for a long time.
- Sufficient loading in resistance exercise is beneficial for long-term 1-RM gains.

1. Introduction

The aging process is characterized by progressive declines in muscle mass and muscle strength, which ultimately result in a loss of independence. To counteract these detrimental declines, resistance exercise is widely recognized as the most effective approach [1]. World-leading organizations in exercise prescription have recommended to train at relatively high intensities of load, i.e. 65% to 80% of the one-repetition maximum (1-RM) [2, 3]. Even though the effects of high-load resistance exercise are well-documented, older adults might feel less confident using high loads.

In an attempt to minimize loads for older persons, low-load resistance exercise protocols (<60% of 1-RM) have been introduced and compared to traditional high-load exercise (≥65% of the 1-RM). The growing amount of reviews and meta-analyses underline the potential of low-load resistance exercise to improve muscle mass and strength in previously untrained individuals [4-7]. More specifically, when matched for total training volume (i.e. sets x %load x repetitions) and performed until volitional fatigue, low-load resistance exercise can induce similar gains in muscle mass as high-load resistance exercise [8-10]. The only clear and consistent performance-related benefit of high-load over low-load resistance exercise seems to be the higher gains in 1-RM of the trained movement [11-15]. These results suggest that practice with a sufficiently high mechanical stimulus (i.e. load) is necessary to maximize gains in 1-RM strength, probably because of movement- and load-specific neural adaptations during training. Interestingly, we have previously shown that this mechanical stimulus can also be created by increasing the load at the end of a high-repetition low-load exercise set without exceeding 50% of 1-RM [8]. Combined with the finding that the use of high loads is not necessarily superior to low loads for improvements in functional performance and non-specific strength [8, 12, 16], a strong case can be made for the use of low loads in resistance exercise protocols for older adults. However, an important remark is that there might be a threshold load for sustained submaximal contractions below which subsequent recruitment of larger motor units is not produced because of the recovery capacity of utilized motor units. This would prevent true muscle fatigue from ever being reached, resulting in suboptimal adaptations. To date, no research has been able to identify this specific load, which is likely different per individual [7].

Although the number of studies on high- versus low-load resistance exercise has expanded in the last years, detraining studies are virtually non-existing. To the authors' knowledge, only one study has focused on the effects of detraining after a period of high- and low-load resistance exercise [17]. This study suggested that gains in 1-RM strength and functional performance are better maintained after high- compared to low-load resistance exercise throughout several months of detraining. Other studies that have examined the influence of training load on muscle strength and/or muscle mass loss following a detraining period in older adults used relatively high loads ≥ 60% of 1-RM. Therefore, these studies do not add information to the comparison of high and low loads [17-19]. The lack of detraining studies with older adults is unfortunate since periods of training interruptions are likely due to motivational and/or health-related issues. Therefore, more insight in the effects of detraining are crucial to evaluate the overall potential of low- compared to high-load resistance exercise.

To address this gap in the literature, the current study evaluated the effects of a 24-week detraining period that followed 12 weeks of high- and low-load resistance exercise in older adults. Previously, we have reported the post-intervention gains in muscle size, muscle strength and functional performance, which was the primary focus of the intervention [8]. Two low-load exercise protocols were designed and compared to high-load exercise (HIGH, 80% 1-RM): 1) a low-load protocol (LOW, 20% 1-RM) in which load was kept constant within the training set, and 2) a mixed low-load protocol (LOW+, 20% 1-RM and 40% 1-RM) in which load was increased within the training set after 60 repetitions. This mixed-low resistance exercise protocol was designed to overcome the potential problem of a threshold load needed to reach true muscle fatigue at the end of a training set. Increasing the load at the end of a high-repetition low-load protocol might be a strategy to make it easier to reach volitional muscle fatigue. Briefly, all protocols resulted in similar gains in muscle size, isometric strength and functional performance, but 1-RM gains were higher in HIGH and LOW+ compared to LOW [8]. Given the similarity of post-intervention gains in most of the outcome measurements, we hypothesized that the decline rate after 24-weeks of detraining would be comparable between groups.

2. Methods

2.1.Trial design

This randomized trial was designed as a parallel-group study, with three different resistance exercise interventions. The intervention duration was 12 weeks. At the end of the intervention, participants were asked if they could be contacted in the future for further testing. They all agreed, but they were blind to our intention to perform follow-up testing after 24 weeks. There was no contact between participants and researchers between post-intervention and follow-up measurements. This approach was used so that motivational factors could be investigated after cessation of the intervention [20]. In order to obtain information on detraining, only the follow-up results of the participants who returned to baseline levels of daily-life physical activity without any involvement in strength training post-intervention were analyzed in the current study (see flow diagram in Fig. 1).

In all analyses, ‘pre’ refers to the time point before the intervention (January to March 2012), ‘post’ to immediately after the 12-week intervention (April to June 2012), and ‘follow-up’ to 24 weeks after the end of the intervention (October to December 2012). The study was approved by the Human Ethics Committee of KU Leuven in accordance with the declaration of Helsinki. Informed consent was obtained from all participants included in the study.

2.2.Participants

Participants who participated in the intervention study were 56 community-dwelling older adults between 60 and 80 years old (68.0 ± 5.0 years). Exclusion criteria were contraindications for maximal strength testing, neuromuscular disorders or recent training experience (described elsewhere in detail) [8]. As shown in Figure 1, not all participants completed the measurements at follow-up. Data of all participants who performed at least one follow-up measurement (N = 42) are included in the current study.

2.3.Randomization

After stratification for gender, age and baseline knee extensor isometric strength, participants were randomly assigned to one of three intervention conditions by drawing straws: traditional high-load resistance exercise (HIGH, *n*=18), low-load resistance exercise (LOW, *n*=19), or mixed low-resistance training (LOW+, *n*=19). Allocation ratio was 1:1:1.

2.4.Resistance training intervention

Training was performed three times weekly on nonconsecutive days over a period of 12 weeks (total of 36 sessions). Exercises performed were the bilateral leg press, leg extension and seated row (Technogym, Gambettola, Italy), but the present study focused on outcomes of the lower limb. The applied training protocols have previously been described in detail [8]. HIGH performed two sets of 10 to 15 repetitions. Resistance was initially set at about 80% of one repetition maximum (1-RM). One minute of rest was provided between sets. LOW performed one set of 80 to 100 repetitions. Resistance was initially set at about 20% of 1-RM.

LOW+ performed a fatiguing protocol of 60 repetitions at an initial resistance of 20% of 1-RM, immediately followed (no rest) by 10 to 20 repetitions at an initial resistance of 40% of 1-RM. 1-RM strength tests were performed every 4 weeks to calculate training loads. In all groups, participants were encouraged to continue the exercise until volitional fatigue. Loads were adjusted if participants performed repetitions beyond the prescribed training zone, as well as if the rate of perceived exertion dropped below 6 (scale from 0 to 10).

2.5.Outcome measures

Muscle volume – A computed tomography scan (Siemens Somatom Definition Flash, Forchheim, Germany) was used to measure muscle volume (MV) of the right upper leg. Four 2.5mm-thick axial images were obtained at the midpoint of the distance between the medial edge of the greater trochanter and the intercondyloid fossa of the femur. Standard Hounsfield Units ranges for skeletal muscle (0-100) were used to segment muscle tissue area, and corrections were made for bone marrow. The four slices were put together as one 10mm-thick slice, and the software program Volume (Siemens) was used to calculate the total muscle volume (cm³) of the 10mm-thick slice. Test-retest reliability in our lab: ICC 0.99, CV% 1.3.

All measurements were performed in the University Hospital by one expert radiologist who was blinded to group allocation.

One-repetition maximum – One-repetition maximum (1-RM) was measured on the leg press. Testing procedures have previously been described in more detail [8].

Isometric and isokinetic muscle strength – Isometric and isokinetic strength of the knee extensors were unilaterally measured on a Biodex Medical System 3® dynamometer (Biodex Medical Systems, Shirley, NY). Tests were performed on the right side, unless there was a medical contraindication. Participants were seated on a backwardly-inclined (5°) chair. Their position was stabilized with safety belts across the upper leg of the test side, the hips, and the shoulders. The rotational axis of the dynamometer was aligned with the transversal knee-joint axis and was connected to the tibia with a length-adjustable lever arm. Range of motion was set from a knee joint angle of 90° to 160° (180° represents full extension). All settings were identical at pre, post, and follow-up. The protocol, as described below, was performed twice and the best result was reported.

First, isometric or static strength of the knee extensors was determined as the highest peak torque (Nm) produced during two maximal voluntary isometric contractions (5 second duration) at a knee joint angle of 120°. Test-retest reliability in our lab: ICC 0.94, CV% 7.8.

Second, isokinetic or dynamic strength of the knee extensors was measured by performing a series of three consecutive maximal concentric extension-flexion movements at a movement velocity of $60°s^{-1}$, followed by five movements at both $180°s^{-1}$ and $240°s^{-1}$. The dynamic peak torque (Nm) of the knee extensors, irrespective of knee angle, was recorded as $PT_{dyn60°s}{}^{-1}$, $PT_{dyn180°s}{}^{-1}$, and $PT_{dyn240°s}{}^{-1}$, respectively. Test-retest reliability in our lab: ICC 0.94-0.96, CV% 6.3-7.6.

Muscle quality – Muscle quality of the upper leg was calculated as the knee extensor isometric peak torque divided by muscle volume of the upper leg, expressed in Nm/cm³.

Functional performance – The following tests were performed: 6-minute walk test, maximal gait speed test over a distance of 7.5m, 30-second chair sit-to-stand test, 5-repetition chair sit-to-stand test, and timed up-and-go test. Tests have previously been described in detail [8].

2.6.Statistical analyses

Data were initially analyzed for normality with a Shapiro-Wilk test. Of the muscular and functional outcome variables, the following were positively skewed: muscle volume, 1-RM, $PT_{dyn60°s}{}^{-1}$, $PT_{dyn180°s}{}^{-1}$, and $PT_{dyn240°s}{}^{-1}$, and 5-repetition chair sit-to-stand test. To meet the assumptions for the use of parametric analyses, positively-skewed data were normalized with base 10 log transformations.

Equivalence between participants who completed all follow-up tests (compliers) and those who did not (non-compliers) was assessed using independent samples t-tests. A chi-square test was used to determine if the number of non-compliers differed between groups.

Baseline differences between groups were assessed with one-way analysis of variance (ANOVA). Within-group changes from post to follow-up and from baseline to follow-up were analyzed with paired t-tests. To assess between-group differences in changes over time, repeated measures ANOVA was used, with time as within factor and group as between factor (3 time x 3 groups). Effect sizes (partial eta squared (η_p^2)) were calculated for the main effect of time and for the time-by-group interaction effect, where small (<0.06), medium (≥0.06 and < 0.14) and large (≥0.14) effect sizes were identified. One-way ANOVA with LSD post hoc tests were used to determine which groups differed in relative changes (%) over time.

Average training volume per exercise session was calculated as follows:

$$\frac{\sum_{i=1}^{n}(\text{number of repetitions leg press} \times \%1\text{-RM})i + (\text{number of repetitions leg extension} \times \%1\text{-RM})i}{n}$$

with n = total number of exercise sessions performed during the 12-week training intervention. As previously published data already showed a higher average training volume in LOW compared to HIGH and LOW+ [8], this variable was introduced as a covariate in the repeated measures ANOVA.

All statistical tests were executed with SPSS software version 24 (SPSS Inc., Chicago, IL). Level of significance was set at *p*<0.05.

3. Results

3.1. Training adherence, loss to follow-up and baseline characteristics

Training adherence during the initial 12-week intervention was previously reported and did not differ between groups [8]. None of the participants' characteristics (Table 1) nor any of the outcome variables differed significantly between groups at baseline (all *p*>0.05)

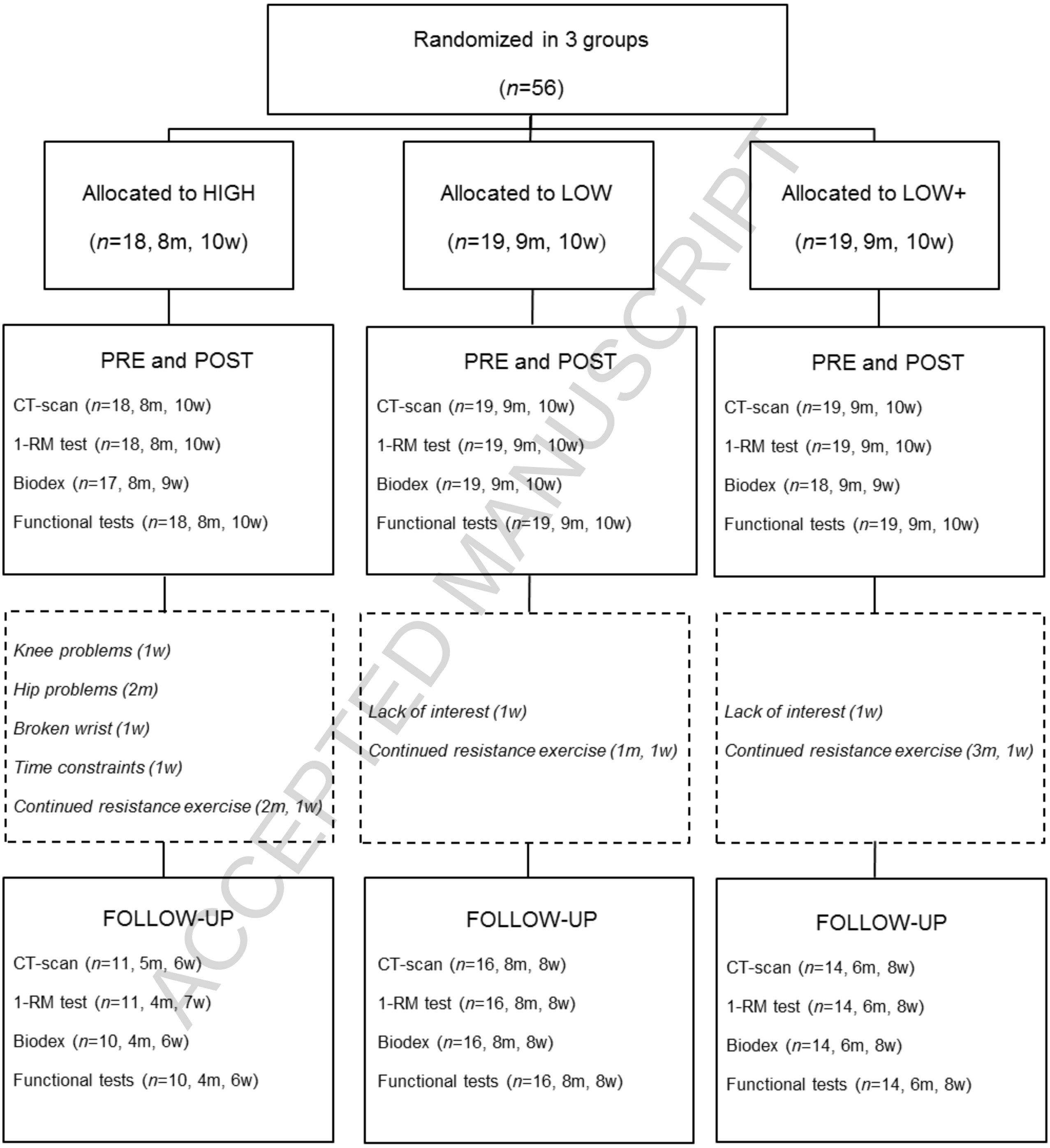

Fig. 1 Flowchart of the study

Table 1 Means ± SD for subjects' characteristics at baseline

		HIGH (*n*=10-12: 4-5m, 6-7w)	LOW+ (*n*=16: 8m, 8w)	LOW (*n*=14: 6m, 8w)	*p*
General information	Age (yrs)	68.8 ± 4.1	66.8 ± 5.6	68.7 ± 4.0	0.454
	Weight (kg)	69.0 ± 9.9	76.7 ± 11.7	76.2 ± 15.2	0.248
	Height (m)	1.66 ± 0.09	1.67 ± 0.09	1.66 ± 0.10	0.978
	BMI (kg/m^2)	25.1 ± 2.7	27.6 ± 3.0	27.5 ± 4.3	0.133
Muscle volume and strength	Muscle volume (m^3)	147.0 ± 36.5	150.8 ± 37.5	154.7 ± 34.8	0.861
	1-RM leg press (kg)	88.1 ± 56.1	90.9 ± 34.4	108.2 ± 49.0	0.467
	Isometric muscle strength (120°) (Nm)	128.4 ± 42.6	140.3 ± 42.3	140.9 ± 44.3	0.759
	Isokinetic muscle strength (60°s^{-1}) (Nm)	111.7 ± 35.4	127.3 ± 36.9	129.9 ± 46.9	0.552
	Isokinetic muscle strength (180°s^{-1}) (Nm)	70.9 ± 23.7	81.5 ± 25.0	83.0 ± 30.3	0.539
	Isokinetic muscle strength (240°s^{-1}) (Nm)	63.5 ± 20.4	73.5 ± 23.3	72.9 ± 25.8	0.567
	Muscle quality (Nm/cm^3)	0.87 ± 0.15	0.93 ± 0.16	0.91 ± 0.16	0.610
Functional performance	6min walk distance (m)	585.0 ± 78.8	574.1 ± 95.8	557.2 ± 95.8	0.671
	Maximal gait speed (ms^{-1})	1.71 ± 0.25	1.83 ± 0.34	1.95 ± 0.28	0.136

30-second sit-to-stand (number of reps)	14.9 ± 2.1	15.1 ± 2.1	16.1 ± 2.1	0.321
5-repetition sit-to-stand (s)	9.8 ± 1.9	9.4 ± 1.7	9.3 ± 1.7	0.763
Timed up-and-go (s)	6.1 ± 0.9	6.2 ± 0.8	5.9 ± 0.9	0.631

HIGH = high-load resistance exercise; LOW+ = mixed low-load resistance exercise; LOW = low-load resistance exercise;

p-values: results of one-way analysis of variance between baseline group means.

Figure 1 shows a detailed flow diagram of the study. Two Biodex measurements (one baseline for HIGH, one post for LOW+) failed due to a lack of compliance of the participants with the test instructions, and were excluded from analysis [8]. None of the participants in HIGH, LOW or LOW+ dropped out during the 12-week intervention study. One participant in LOW refused to participate in any of the follow-up tests. Not all of the remaining participants completed all follow-up tests. Reasons for non-compliance are reported in Figure 1. The woman in HIGH who did not comply at follow-up because of knee problems already reported symptoms of osteoarthritis before the start of the intervention without aggravation of symptoms post-intervention. The men in HIGH with knee or hip problems at follow-up did not report joint problems pre- or post-intervention. Only a minority of participants continued strengthening exercises after cessation of the intervention and were excluded in the follow-up measurements: 3 out of 18 participants in HIGH, 4 out of 19 participants in LOW+, and 2 out of 18 participants in LOW. No adverse effects of the intervention were reported in any of the groups [8]. The number of participants that were lost to follow-up did not differ between groups (p>0.05). In addition, those lost to follow-up were representative of the overall sample (baseline values and post-intervention gains).

3.2.Outcome measurements

All immediate post-intervention results were previously reported [8] and were therefore not repeated in the current study. However, the level of significance was added for the changes from pre- to post-intervention in Tables 2-3.

Muscle volume – Muscle volume of the upper leg changed significantly over time (p<0.001), with no differences between groups (p=0.663). After a post-intervention increase, muscle volume returned to baseline values in all groups after the 24-week detraining period (Table 2, Fig. 2a).

One-repetition maximum –A group-by-time interaction effect was found for leg press 1-RM (*p*=0.015). A similar rate of decline from post-intervention to follow-up was found in the three groups (-7.2% to -10.9%). Despite these statistically significant declines, substantial strength retention above baseline values was demonstrated in all groups (all *p*<0.05). Interestingly, the residual 1-RM gain from baseline to follow-up was significantly lower in LOW (+12.3 ± 7.3%) than in HIGH (+34.9 ± 38.3%, *p*=0.005) and tended to be lower in LOW than in LOW+ (+24.3 ± 17.7%, *p*=0.081) (Table 2, Fig. 2b).

Isometric and isokinetic muscle strength and muscle quality – For isometric strength, a time-effect was found (*p*<0.001), whereas no group-by-time effect was revealed (*p*=0.931). After an initial post-intervention gain, no significant decreases in isometric strength were found from post to follow-up (all *p*>0.05). Overall, isometric strength exceeded baseline values at follow-up (*p*=0.007), although not significantly within the three groups separately (all *p*>0.05). Similar results were found for muscle quality: an overall time-effect (*p*<0.001) without a group-by-time interaction effect (*p*=0.881). No significant declines were shown from post-training to follow-up and muscle quality was significantly higher at follow-up compared to baseline for the total study sample (*p*=0.021).

Results also revealed a trend towards or a significant time-effect for $PT_{dyn60°s}{}^{-1}$ (*p*=0.089) and $PT_{dyn180°s}{}^{-1}$ (*p*<0.008), with no group-by-time effect (*p*=0.607 for $PT_{dyn60°s}{}^{-1}$ and *p*=0.500 for $PT_{dyn180°s}{}^{-1}$). At follow-up, no changes compared to baseline were found in any of the groups for $PT_{dyn60°s}{}^{-1}$ and $PT_{dyn180°s}{}^{-1}$ (all *p*>0.05) (Table 2). $PT_{dyn240°s}{}^{-1}$ changed over time (*p*=0.011) and this change differed between groups (trend, *p*=0.065). After a greater, though not statistically significant, post-intervention gain in HIGH compared to LOW and LOW+, HIGH decreased more from post to follow-up than LOW+ (*p*=0.004) and LOW (*p*=0.065). Similar to isokinetic strength at lower speeds, no strength retention above baseline levels was shown for $PT_{dyn240°s}{}^{-1}$ in any of the groups (all *p*>0.05) (Table 2).

Table 2 Percent changes for muscle volume and muscle strength in the three intervention groups

		% Changes		Time		Time x group	
Outcome measures	Baseline to post	Post to follow-up	Baseline to follow-up	p	η_p^2	p	η_p^2
Muscle volume				**<0.001**	**0.288**	0.663	0.031
HIGH	+3.2 ± 3.2*	-2.6 ± 3.3*	+0.4 ± 2.1				
LOW+	+2.6 ± 4.1*	-1.6 ± 2.2*	+0.5 ± 3.2				
LOW	+2.6 ± 2.9*	-1.7 ± 3.7	+0.8 ± 3.9				
1-RM leg press				**<0.001**	**0.684**	**0.015**	**0.159**
HIGH	+51.3 ± 38.9*†	-10.9 ± 8.4*	+34.9 ± 38.3*†				
LOW+	+38.7 ± 21.6*†	-9.4 ± 11.1*	+24.4 ± 17.7*				
LOW	+23.0 ± 20.8*	-7.2 ± 9.9*	+12.3 ± 7.3*				
Isometric muscle strength (120°)				**<0.001**	**0.323**	0.931	0.012
HIGH	+12.1 ± 8.3*	-4.5 ± 8.5	+8.3 ± 12.0				
LOW+	+7.7 ± 8.4*	-1.3 ± 9.5	+4.3 ± 10.6				
LOW	+8.7 ± 9.8*	-3.1 ± 8.0	+5.2 ± 11.5				
Isokinetic muscle strength (60°s^{-1})				0.089	**0.069**	0.607	0.040

HIGH	+5.0 ± 7.8	-1.8 ± 5.3	+3.8 ± 11.2				
LOW+	+1.8 ± 10.2	+2.3 ± 7.6	+1.4 ± 9.7				
LOW	+5.5 ± 9.2*	-2.7 ± 9.3	+2.2 ± 8.3				
Isokinetic muscle strength (180°s^{-1})				**0.008**	**0.132**	0.500	0.049
HIGH	+6.6 ± 8.2*	-0.5 ± 9.3	+6.3 ± 11.8				
LOW+	+2.4 ± 5.0	+4.0 ± 8.8	+3.7 ± 7.2				
LOW	+3.6 ± 7.1	-1.5 ± 8.8	+1.6 ± 6.2				
Isokinetic muscle strength (240°s^{-1})				**0.011**	**0.123**	0.065	**0.124**
HIGH	+7.1 ± 9.4	-6.7 ± 6.5*	+0.4 ± 8.5				
LOW+	+2.4 ± 5.5	+3.2 ± 8.4‡	+3.6 ± 7.9				
LOW	+2.7 ± 6.1	-1.3 ± 8.5	+1.1 ± 7.1				
Muscle quality				**0.001**	**0.172**	0.973	0.007
HIGH	+10.1 ± 8.7*	-1.5 ± 8.2	+8.2 ± 11.7				
LOW+	+5.2 ± 10.3*	+0.7 ± 10.2	+3.8 ± 10.2				
LOW	+6.1 ± 10.6*	-1.3 ± 8.9	+4.5 ± 12.4				

HIGH = high-load resistance exercise; LOW+ = mixed low-load resistance exercise; LOW = low-load resistance exercise. P-values and η_p^2 represent results of repeated measures ANOVA, time x group effect was corrected for average training volume during the intervention. P-values < 0.05 and $\eta_p^2 > 0.06$ are marked in bold.

* Significant within-group change ($p<0.05$)

† Significant difference with LOW ($p<0.05$)

‡ Significant difference with HIGH ($p<0.05$)

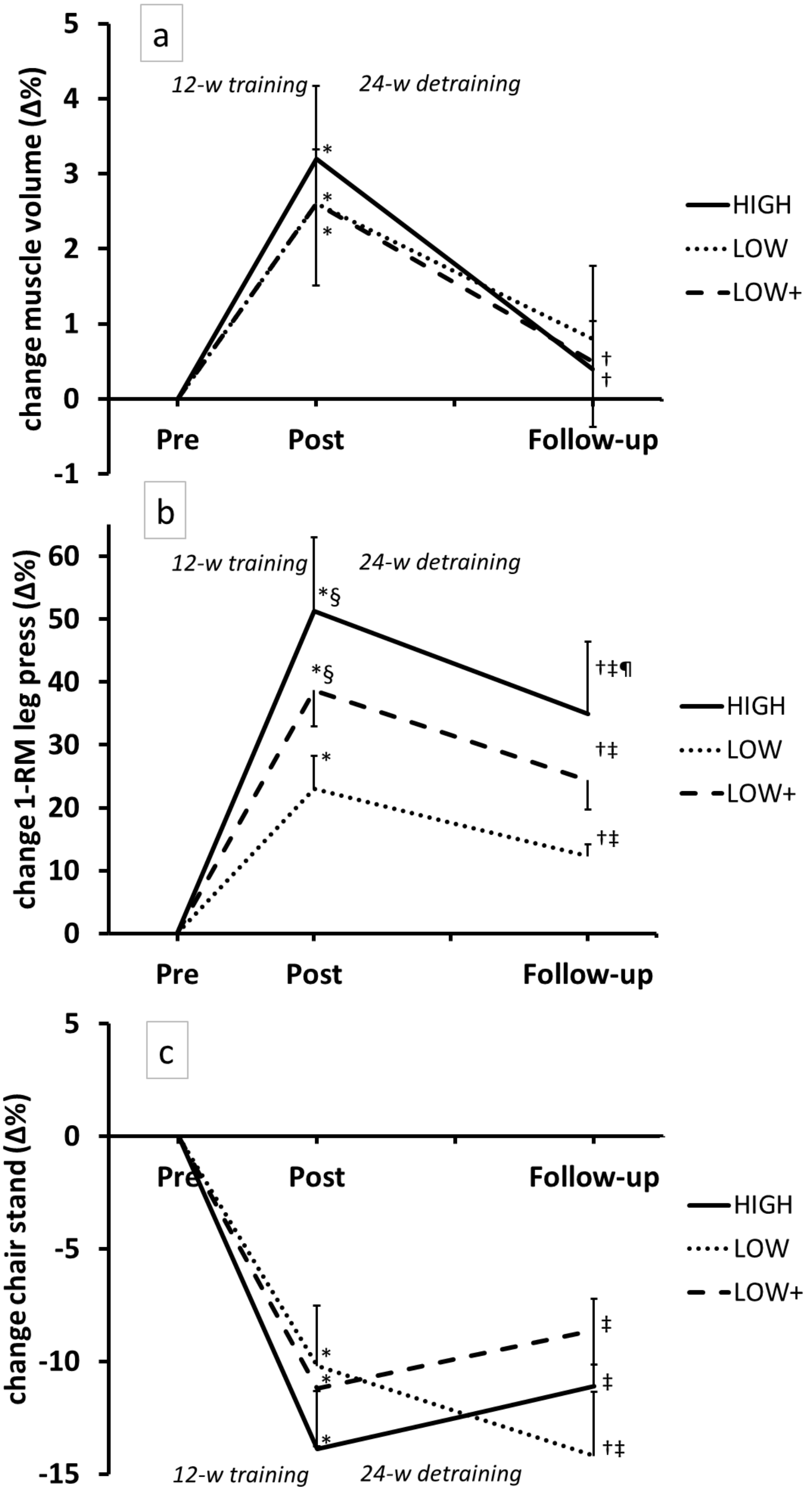

Fig. 2 Percent changes over time with respect to baseline values in muscle volume (a), leg press 1-RM (b) and 5-repetition chair stand test (c) for high-load resistance exercise (HIGH),

low-load resistance exercise (LOW), and mixed low-load resistance exercise (LOW+). *Significant change from baseline to post. †Significant change from post to follow-up. ‡Significant change from baseline to follow-up. §Significant difference with LOW from baseline to post. ¶Significant difference with LOW from baseline to follow-up. Error bars represent 1SE (for clarity, SE is visualised in only one direction)

Functional performance – An overall time effect was found for all functional performance tests (all $p<0.05$), indicating training-induced improvements [8]. These training-induced improvements were maintained for almost all functional performance tests (see Table 3, Fig. 2c). No group-by-time effects were found for any of the functional performance tests (all $p>0.05$), although a trend was shown for maximal gait speed. HIGH showed greater post-intervention gains than LOW and LOW+, which were maintained compared to LOW at follow-up.

Table 3 Means ± SD at baseline and percent changes for functional performance in the three intervention groups

	%Change			Time		Time x group	
Outcome measures	Baseline to post	Post to follow-up	Baseline to follow-up	p	η_p^2	p	η_p^2
6-minute walk distance				**<0.001**	**0.227**	0.912	0.013
HIGH	+6.5 ± 5.3*	-1.5 ± 4.1	+4.8 ± 4.5*				
LOW+	+4.8 ± 12.0	-0.0 ± 4.9	+4.5 ± 9.6				
LOW	+5.2 ± 8.5*	+0.0 ± 7.4	+5.0 ± 8.7*				
Maximal gait speed				**<0.001**	**0.255**	0.076	**0.112**
HIGH	+15.3 ± 13.9*	+0.2 ± 5.3	+15.1 ± 11.7*				
LOW+	+2.8 ± 13.0†	+5.8 ± 9.3*	+8.2 ± 11.7*				
LOW	+3.2 ± 11.7†	+1.1 ± 9.1	+3.5 ± 6.9†				
30-second chair sit-to-stand				**<0.001**	**0.292**	0.364	0.057
HIGH	+10.2 ± 8.5*	-0.5 ± 8.9	+9.3 ± 7.2*				
LOW+	+9.3 ± 9.3*	-1.2 ± 8.7	+7.5 ± 9.1*				
LOW	+3.0 ± 7.9	+4.3 ± 9.5	+7.4 ± 11.5*				
5-repetition chair sit-to-stand				**<0.001**	**0.477**	0.263	**0.069**

HIGH	-13.9 ± 8.2*	+3.0 ± 8.3	-11.1 ± 12.2*				
LOW+	-11.2 ± 9.6*	+3.9 ± 11.8	-8.6 ± 5.7*				
LOW	-10.2 ± 10.7*	-4.3 ± 7.9*	-14.2 ± 11.4*				
Timed up-and-go				**0.043**	**0.082**	0.923	0.012
HIGH	-3.7 ± 7.9	+4.3 ± 6.4	+0.3 ± 9.3				
LOW+	-2.0 ± 11.7	+0.5 ± 8.0	-2.1 ± 9.4				
LOW	-4.4 ± 7.9*	+1.9 ± 10.4	-2.7 ± 11.1				

HIGH = high-load resistance training; LOW+ = mixed low-load resistance training; LOW = low-load resistance training. η_p^2 represent results of repeated measures ANOVA, time x group effect was corrected for average training volume during the intervention. P-values < 0.05 and η_p^2 > 0.06 are marked in bold.

* Significant within-group change (*p*<0.05)

† Significant difference with HIGH (*p*<0.05)

4. Discussion

The objective of the present study was to compare the detraining effects after 12 weeks of high- and low-load resistance exercise on muscular and functional outcomes in older adults. The study revealed that training load did not affect decline rates in muscle volume, which returned to baseline levels after 24 weeks of detraining. In addition, training-induced gains in isometric strength and functional capacity were maintained, independent of training load. A similar decline rate in 1-RM was shown after detraining, but the greater gain from intervention in HIGH and LOW+ led to a greater improvement at follow-up compared to baseline. The findings of this study provide important information for practitioners aiming at prescribing the most appropriate exercise protocol for an older individual.

With regard to muscle volume, post-exercise muscle hypertrophy was negated after 24 weeks of detraining. This finding is consistent with previous research, in which muscle volume returned to pre-training values 24 to 31 weeks after cessation of a resistance exercise intervention [21-23]. Even after a shorter detraining period of 12 weeks, a complete loss of the initial training-induced gain in muscle volume has been reported [24, 25].

In the current study, the loss in muscle volume and the level of muscle volume 24 weeks after the intervention were independent of prior training resistance. This result is in contrast with the findings of Tokmakidis et al. [18]. After a 12-week detraining period, their study showed a slightly greater decline but still greater retention in mid-thigh cross-sectional area after high-load exercise (80% of 1-RM) compared to moderate-load exercise (60% of 1-RM). However, they also found greater post-intervention hypertrophy after high-load exercise, probably because exercise protocols were not designed to reach muscular failure. If exercises are not performed until failure, high external resistances are preferred for activation of the type II fibers, which are known to be more responsive to hypertrophy [26].

Although a reversal in hypertrophy occurred in the current study, muscle strength gains were partly preserved in all groups. In other words, with the same amount of muscle volume, participants were able to generate higher levels of strength at follow-up compared to baseline, which is reflected in improved muscle quality. These results are consistent with former research showing that exercise-induced adaptations in muscle strength are maintained longer than muscle hypertrophy after training cessation [21-23, 27-29, 24, 25]. As stated by Buckner and colleagues, and confirmed in the current study, the consistent maintenance of strength despite loss of muscle mass provides evidence that these adaptations are largely independent of each other and that neural adaptations are crucial contributors to strength gains [30].

Training-induced gains in 1-RM were greater in HIGH and LOW+ compared to LOW, as reported earlier [8]. Given that the three loading schemes experienced similar losses in 1-RM after detraining, the residual gain from baseline to follow-up remained greater in HIGH and LOW+ compared to LOW. The decline rates are in agreement with the -10.8% decline in 1-RM reported in older adults by Trappe and coworkers after 24 weeks of detraining [21]. Our data suggest that higher external loads are preferred to maximize 1-RM gains in the long-term. In agreement with our findings, the detraining study of Fatouros et al. showed that 1-RM strength gains are maintained for a longer period of time after high- compared with low-load resistance exercise [17].

In addition to 1-RM strength tests, the current study included standardized isometric and isokinetic tests measured by a motor-driven dynamometer. None of the resistance exercise protocols was advantageous over another for maintaining isometric or isokinetic strength gains after detraining. Although none of the groups showed a detraining decrease in isometric strength, values no longer exceeded baseline levels in any of the groups separately. This is in contrast with previous research [29, 21] and might be due to our limited sample size in the three groups at follow-up, which makes our study susceptible to type II error. If all participants are combined in one group, data do confirm a long-term improvement in isometric strength compared to baseline. With regard to isokinetic strength at 240°s^{-1}, HIGH seemed most beneficial for immediate post-intervention gains [8]. However, HIGH demonstrated a higher rate of decrease in high-speed isokinetic strength after detraining compared to LOW and LOW+, with no longer-lasting effect on velocity-dependent strength.

In the current study, functional performance levels at follow-up exceeded baseline values in all groups, even though our participants were already well-functioning before the start of the intervention. Although this result is consistent with the findings of Häkkinen and colleagues [22], a number of detraining studies failed to demonstrate maintenance in gains of functional performance [31-33]. This might be due to differences in the study sample with respect to age, gender and functional status. In agreement with our findings, previous meta-analyses already stated that high loads are not necessarily superior to low loads for improving functional performance [16, 34]. Our study adds to the literature by showing no superior results for high loads also after a detraining period. Considering that periods of training interruptions are likely, the results of this study are of major importance to evaluate the overall potential of low-load resistance exercise.

Important to note is that the use of low loads in resistance exercise demands training to volitional fatigue to maximize motor unit recruitment and optimize training adaptations. Compared to high-load exercise, low-load exercise protocols are characterized by a longer time under tension preceding a maximal effort. As a consequence of this longer time under tension, low-load resistance exercise has been shown to result in higher degrees of discomfort compared to high-load resistance exercise [35]. Although some participants might be more encouraged to train at low loads because of fear for overloading, others might prefer the use of higher loads because of the lower degree of perceived discomfort. This study is not intended as a plea for the use of low-load resistance exercise in an older population; rather, we aim at improving our understanding on the potential of different loading schemes in clinical practice.

A limitation of the current study is the loss of participants from post to follow-up due to the primary focus on investigating long-term adherence and motivation [20], which disallowed instructing participants to discontinue any type of resistance exercise. This also prevented the possibility of having multiple test periods within the 24-week detraining period which could have provided more detailed insight into detraining progression after each type of strength training. Another limitation is that this study only focused on muscle volume, muscle strength and functional capacity. Other clinically relevant outcomes, such as cardiovascular and metabolic health, were beyond the scope of the current study. However, they deserve attention in future research.

In conclusion, this study underlines the importance of performing strength training at old age. When training is performed until volitional fatigue, gains in functional capacity and isometric strength can be maintained for a long time, independent of prior training load. The only clear long-term performance benefit of HIGH and LOW+ over LOW is the 1-RM gain, which is very specific to the trained movement and is not translated to improved overall function. These findings underline the potential of low-load resistance exercise protocols in older age as an alternative to high-load resistance exercise or as variation in training approaches. However, to maintain training-induced improvements in muscle volume, long-term participation in resistance exercise is recommended.

Conflict of interest

The authors declare no conflicts of interest.

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