Experimental Gerontology 120 (2019) 6–14

Contents lists available at ScienceDirect

Experimental Gerontology

journal homepage: www.elsevier.com/locate/expgero

Bench stepping with incremental heights improves muscle volume, strength and functional performance in older women

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ARTICLE INFO

Section Editor: Christiaan Leeuwenburgh

Keywords:
Functional training
Strength training
Balance
Sarcopenia
Weight bearing exercise
Muscle hypertrophy

ABSTRACT

Aim: Task-specific exercises such as bench stepping can improve functional ability and reduce falling incidents in older adults. However, such exercises are often not optimized to improve muscle volume and force-velocity characteristics. This study determined the effects of a 12-week stepping program using incremental step heights (STEEP), on muscle volume, strength, power, functional ability and balance performance in older women.
Methods: Forty-five community-dwelling women (69y ± 4) were randomly assigned to the STEEP group or a non-training CONTROL group. Training intensity was primarily determined by step height, while training volume remained equal. Thigh muscle volume (CT-scan), force-velocity characteristics of the knee extensors (Biodex dynamometer) and functional ability (Short Physical Performance Battery, timed stair ascent, 10-m walk test and countermovement jump height) were determined pre- and post-intervention. In addition, 3D trunk accelerations were recorded at the lower back to assess balance during the Short Physical Performance Battery balance tests.
Results: Two-way ANOVA showed that the STEEP program increased thigh muscle volume, knee extensor isometric peak torque, dynamic peak power, unloaded rate of velocity development and improved performance on all functional tests to a greater extent than CONTROL ($p < .05$), except the countermovement jump. No improvements were found for peak velocity and balance performance ($p > .05$).
Conclusion: Our results indicate that bench step training with incremental step heights simultaneously improves functional ability, thigh muscle volume and force-velocity characteristics of the knee extensors in older women.

1. Introduction

The age-related loss of muscle volume, strength and power is an important predictor for fall risk, loss of mobility and independence in older adults (Pijnappels et al., 2008a; Liu and Latham, 2009). This loss of muscle volume is accelerated after menopause (Cederholm et al., 2013), making women particularly susceptible. Moreover, strength and power decrease to a much larger degree than can be explained by the loss of muscle volume alone (Van Roie et al., 2011). Therefore, it is imperative to maintain muscle volume, strength and power for as long as possible. Engaging in physical activity can prevent and even reverse the muscular and functional declines (Granacher et al., 2008). Currently, most training interventions appear to maintain a dichotomous approach, employing resistance exercise to improve muscle characteristics and task-specific exercise to improve functional performance. However, few studies have explored if exercises can be adapted to target muscle characteristics and functional performance simultaneously.

Resistance exercise is generally considered most effective in improving muscle volume and strength (Cederholm et al., 2013; Sherrington et al., 2011). However, improvements in muscle strength through resistance training alone do not necessarily translate to improvements in functional performance (Orr et al., 2008; Cress et al., 1996; Manini et al., 2007), likely because training adaptations in older adults are highly task-specific to activities of daily life (e.g. stepping and obstacle navigation) (Manini et al., 2007; Bice et al., 2011). On the

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https://doi.org/10.1016/j.exger.2019.02.013
Received 6 September 2018; Received in revised form 11 February 2019; Accepted 19 February 2019
Available online 22 February 2019

other hand, training programs based exclusively on functional exercises rarely result in meaningful improvements in muscle volume and strength (Manini et al., 2007; Arampatzis et al., 2011). Therefore, current best practice recommendations include multi-component exercises that target both strength and functional ability (Granacher et al., 2008; Sherrington et al., 2011; Kraemer et al., 2001).

Unfortunately, combining functional exercise with traditional resistance training is not as simple as it might seem. This is due to high avoidance of machine-based resistance training (Martins et al., 2013), preference for other forms of physical activity (Van Roie et al., 2015) and increased exercise duration, which is an important motivational barrier for exercise participation and adherence in older populations (Van Roie et al., 2015; Schutzer and Graves, 2004). Thus, the challenge in designing training programs for older adults is to prescribe time-efficient programs that improve both strength and functional performance with a low motivational threshold for participation.

Bench stepping may simultaneously target strength and functional performance. It is a low-cost exercise that can be performed in both group and home-based settings, seemingly with little to no supervision (although the latter has not yet been properly substantiated) (Salem et al., 2004; Wang et al., 2003; Mair et al., 2014). Bench stepping produces only low to moderate skeletal loading (Mair et al., 2014), and can be performed up to step heights of 47 cm by older women, without the use of external support (Cress et al., 1996). Additionally, the training intensity can easily be modified by altering step height (Mair et al., 2014). In a non-fatigued state, a minimum step height of 20 to 30 cm was required to achieve electromyography (EMG) amplitudes comparable to resistance exercise at 60% of one-repetition maximum (1-RM) (Baggen et al., 2017), which is the recommended training load for strength gains in untrained adults defined by the American College of Sports Medicine (American College of Sports Medicine, 2017). Additionally, lateral stepping with a minimum step height of 30 cm is required to sufficiently activate the hip abductors (Baggen et al., 2017), which is particularly relevant for fall prevention (Orr et al., 2008). Based on these findings, we designed an optimized training program dubbed the ‘Strength Training for Elderly through Elevated stePping’ (STEEP) program, a 12-week task-specific strength training program for older women using incremental step heights exceeding ~18–22 cm step heights which are most common in daily life.

The primary aim of this study was to examine the effects of the STEEP program on muscle volume, force-velocity characteristics, functional performance and balance in older women. Additionally, adherence was tracked and motivation questionnaires were administered in the intervention group to assess the likelihood of long-term training adherence after cessation of the intervention. We hypothesized that thigh muscle volume, knee extensor strength and power, functional performance and balance would be improved. Additionally, we hypothesized that feelings towards the training program would be positive and that perceived enjoyment, feasibility and effectiveness would be high when subjectively compared to traditional resistance exercise.

2. Materials and methods

2.1. Participants

Forty-five sedentary community-dwelling women aged 65 y and older (69 y ± 4) were recruited through advertisements around Leuven, Belgium. Exclusion criteria included participation in a structured training program in the previous 12 months, cardiovascular disease, lower limb prosthetics, arthrosis of the hip or knee, and neurological disease. Participants were assigned to the training group (STEEP; $n = 24$) or the control group (CONTROL; $n = 21$) through a computer-generated randomization scheme, blocked in groups of four, prior to the initial tests. This study was approved by the Human Ethics Committee of KU Leuven, in accordance with the Declaration of Helsinki and registered with the Clinical Trial Center UZ Leuven (S60533). All participants provided signed informed consent before participation.

2.2. Training protocol

The CONTROL group did not participate in training and was asked to maintain their habitual physical activity. The training program performed by the STEEP group is reported below following the Consensus on Exercise Reporting Template (CERT, see Appendix 2 for checklist) (Slade et al., 2016). Training in the STEEP group consisted of 40 min of bench stepping exercise using modular height-adjustable stepping benches, performed 3 times per week for 12 weeks. As previously stated, in a non-fatiguing protocol, EMG amplitudes at step heights of 20 to 30 cm were found to be similar to resistance exercise at 60% of 1-RM (Baggen et al., 2017). However, no guidelines are available with regard to the number of bench-stepping repetitions required to achieve hypertrophy and strength gains. Therefore, we selected the number of repetitions based on previous studies using multi-joint resistance exercises such as the leg press. These found that the number of repetitions to achieve momentary muscle fatigue (failure) on a leg press at 60% 1-RM ranged between 36 and 38 (Hoeger et al., 1990; Shimano et al., 2006). To avoid exceeding this indicated maximum threshold (which may lead to fatigue-related incidents), and to facilitate musical cueing, the number of repetitions per set was fixed to 32. By fixing the number of repetitions for all subjects and intensities, we could also avoid differences in training volume. During the first two weeks of training, individual entry levels (level 1, 3 or 5; Table 1) were determining by assessing the maximum step height at which the participants could complete all sets at the preset pace (~30 steps/min) in both directions. All training sessions were conducted in groups of 8–9 participants by a certified professional fitness instructor in a dedicated fitness room at the faculty of movement and rehabilitation sciences of KU Leuven. Adherence to the training protocol was ensured by the instructor and recorded using a tick list.

Each level encompasses two weeks of training. During week 1 and 2 participants were assigned to their respective baseline level (Pijnappels et al., 2008a; Cederholm et al., 2013; Granacher et al., 2008) and provided with the corresponding progression program. Participants automatically progressed to the next level every time they completed 2 weeks of the previous level. For participants starting at level 5, weighted vests with 5–10% body mass were added to prevent a ceiling effect after achieving the maximum step height of 36 cm. Participants

Table 1
Overview of the STEEP program.

		Step height Fstep (cm)	*Step height Lstep (cm)*	*Body mass Fstep (%)*	*Body mass Lstep (%)*
Level 1	*Week 1*	18	18		
	Week 2	18	18		
Level 2	*Week 1*	24	18		
	Week 2	24	18		
Level 3	*Week 1*	24	24		
	Week 2	24	24		
Level 4	*Week 1*	30	24		
	Week 2	30	24		
Level 5	*Week 1*	30	30		
	Week 2	30	30		
Level 6	*Week 1*	36	30		
	Week 2	36	30		
Level 7	*Week 1*	36	36		
	Week 2	36	36		
Level 8	*Week 1*	36	36	5	
	Week 2	36	36	5	
Level 9	*Week 1*	36	36	5	5
	Week 2	36	36	5	5
Level 10	*Week 1*	36	36	10	5
	Week 2	36	36	10	5

performed 2 × 32 repetitions of stepping in forward direction (Fstep), one set for the right and one set for the left leg. This sequence was repeated in lateral direction (Lstep). After a short break, an identical second set was performed. Each session started with a low-intensity warming-up without using stepping benches and ended with a cooling-down that consisted mainly of stretching exercises.

By assigning individual entry levels, no adjustments were required for differences in training progression due to baseline functional ability or anthropometrics. Initial progression was solely determined by step height. Step height increments were set at 6 cm, starting at 18 cm. The maximum step height was set at 36 cm. If participants progressed past 36 cm step height for both forward and lateral direction, intensity was further increased using weighted vests with 5% or 10% body mass to ensure that a systematic increase in training intensity could be maintained (Wang et al., 2003).

2.3. Outcome measures

2.3.1. Participant characteristics

Participant characteristics were recorded during the pre-tests. Habitual physical activity (PA) was determined using the Godin Leisure-Time Exercise Questionnaire (Godin, 1997). Handgrip strength was recorded using a Jamar handheld dynamometer (Sammons Preston Inc., Bolingbrook, IL, USA). Three measurements were obtained from the dominant hand and the highest value (in kg) was used to indicate maximum grip strength. Test-retest reliability for handgrip strength testing in older adults is well established with an intra-class correlation coefficient (ICC) of 0.91 to 0.95 for the right and left hand respectively (Bohannon and Schaubert, 2005).

2.3.2. Muscle volume

Muscle volume of both legs was obtained within a week pre- and post-intervention using computerized tomography (CT; Somatom Force®, Siemens Medical Solutions, Erlangen, DE). All scans were performed at the same time of day and participants were instructed to lay on the scanning bed for 5 min in supine position prior to the scan. Four 5 mm axial slices were obtained at the midpoint of the distance between the medial edge of the trochanter and the intercondyloid fossa of the femur. These slices were combined and total muscle volume (in cm^3) was determined with custom software developed at the university hospital using standard Hounsfield Units for skeletal muscle (0 − 100). Test-retest reliability evaluated for a similar approach in our lab showed an ICC of 0.99 and a coefficient of variation (CV%) of 1.3 (Van Roie et al., 2017).

2.3.3. Force-velocity characteristics

Torque and velocity of the knee extensors were obtained using a Biodex System 4 Pro® isokinetic dynamometer (Biodex Medical Systems, Shirley, USA; Fig. 1), in accordance with procedures used in previous studies (Van Roie et al., 2011; Van Driessche et al., 2018a).

Testing was performed unilaterally on the dominant side. The range of motion was set between 90° to 160° (full knee extension corresponded to 180°). Isometric strength was assessed by measuring peak torque (in Nm) at knee angles of 120° ($pT_{isom120}$) and 90° (pT_{isom90}). At both angles, participants performed four repetitions of 5 s maximum voluntary contraction, separated by 20 s rest periods. Peak power (pP) and peak velocity (pV) were measured using isotonic contractions. Four ballistic knee extensions were performed against constant resistances. Starting at 90°, participants were instructed to extend their knee four times as fast as possible to 160°. Resistance was consecutively set at 40%, 20%, 0% and 60% of pT_{isom90}. For each resistance, the trials that produced the highest peak power (pP in Nm/s) were used for comparisons of both pP and pV. Additionally, the rate of velocity development (RVD in $°/s^2$) at each resistance was calculated (Van Driessche et al., 2018b). Test-retest reliability in our lab shows an ICC ranging from 0.94 to 0.97 and CV% of 7.8 for the isometric tests (Van Roie et al., 2017; Van Driessche et al., 2018a). Reliability for pP, pV and RVD obtained from isotonic tests was also excellent with an ICC ranging from 0.85 to 0.98 for and CV% ranging from 3 to 9 (Van Driessche et al., 2018b).

2.3.4. Functional and balance performance

Functional and balance performance were assessed using an extended version of the Short Physical Performance Battery (SPPB) (Guralnik et al., 2000). Each of the balance tests (side-by-side, semi-tandem and tandem stance) was recorded three times for 30 s instead of 10 s to allow more accurate assessment of balance performance. SPPB scores were calculated using the first 10 s of each trial. In addition to the 5× sit-to-stand test (5×STS), the functional test battery included a timed 10-m walk test at maximum walking speed (10 MW) and a timed 12-step stair ascent (SA). Each functional test was performed twice and the best performance was used for data analysis. A counter-movement jump (CMJ) was used as an indicator of explosive lower limb muscle power. CMJ height was estimated based on flight time recorded from three separate jumps using a contact mat (Kennis et al., 2013). During all functional tests kinematic data were collected at the lower back using 3D accelerometry (Dynaport MoveTest®, McRoberts, The Hague, NL; Fig. 1). Reliability for SPPB in older adults, instrumented STS in a geriatric population, maximum walking speed, and CMJ in older females was demonstrated in previous studies (Kennis et al., 2013; Schwenk et al., 2012; Freiberger, 2012; Slinde et al., 2008; Bohannon, 1997). Reliability of instrumented SA in our lab was excellent, with an ICC of 0.93 and CV% of 4. To assess balance performance during the static tests of the SPPB, medio-lateral balance performance was assessed using the root mean square of the displacement (mm). Overall balance performance was assessed using the total length of the sway path divided by duration of the measurement (mm/s). Using accelerometry at the lower back, rather than center of pressure measurements, provided us with a way to measure postural sway directly by estimating acceleration of the center of gravity, which is the controlled variable in balance tasks (Panzer et al., 1995), and has been shown to have good reliability (Alsubaie et al., 2018).

2.3.5. Motivation questionnaires

Custom questionnaires (Supplemental material) were completed by the STEEP group during weeks 1, 6 and 12 of the training program. These questionnaires included five questions that assessed feelings related to exercise on a 11-point Likert scale (e.g. 0 = totally disagree, 10 = totally agree) (Van Roie et al., 2015). The internal consistency of these questions was checked with Cronbach's α, where question 3 was inversely coded because of a negative scale. Cronbach's α was 0.64 when all 5 questions were included. However, by removing question 3, Cronbach's α improved to an acceptable value of 0.75, consistent with analyses by Van Roie et al. (Van Roie et al., 2015). Question 3 was therefore removed from this item and treated as a separate item 'relief'. Three additional questions were included to assess the likelihood of training adherence to the STEEP program compared to resistance training. These three items ('enjoyability', 'feasibility' and 'effectiveness') were analyzed separately.

2.3.6. Statistical analyses

Sample sizes were calculated based on the effect size on pT_{isom90} from a previous study using resistance exercise (partial η squared = 0.287) (Van Roie et al., 2013). A total of 38 participants was required to detect a similar effect size with a power of 90% on a two-sided test with $\alpha = 0.05$. Statistical analyses were performed with SPSS (IBM® SPSS v23 Statistics for Windows, Armonk, USA). Data were tested for normality with a Kolmogorov-Smirnov test. Depending on the normality of the data, baseline differences between groups were analyzed using either independent samples *t*-tests or Mann-Whitney *U* tests. In order to check for group x time interaction effects, non-normal data were first log-transformed and all data were subsequently analyzed

Fig. 1. Setup of the isokinetic dynamometer (top left). The timed stair ascent task with lower back-mounted accelerometer (top right). Impression of a training session in week 10 (bottom).

using a mixed ANOVA design with time as within-subjects factor and group as between-subjects factor. If a significant *F*-value was found, within-group changes were analyzed using paired samples *t*-tests. Scores on the motivation questionnaires obtained from the STEEP group were analyzed using a Kendall's W test.

3. Results

3.1. Baseline participant characteristics and adherence

No significant differences in participants' characteristics were found between groups at baseline ($p > .05$; Table 2). Attendance of the training sessions was 90% and all participants were able to complete their assigned progression program. Two participants dropped out between the pre- and post-tests. One participant from the STEEP group dropped out because of excessive sweating, and one from the CONTROL group due to an unscheduled medical procedure (Fig. 2). Even though participants with osteoarthritis were excluded from the study, three participants initially reported light knee pain when stepping at heights exceeding 18 cm. However, after receiving instructions on proper foot placement, these participants indicated no more pain during subsequent training sessions. No further negative effects were reported.

3.2. Muscle volume

A significant group × time interaction effect was found for relative change of muscle volume. Muscle volume increased significantly in the STEEP group (2.8% for the right leg and 2.6% for the left leg). No significant differences were detected in the CONTROL group (Table 3).

Table 3: Mean and standard deviation of muscle volume and force-velocity characteristics of the knee extensors pre- and post-intervention with % change, mean difference (95% confidence interval; CI), significance of difference and effect sizes.

3.3. Force-velocity characteristics

Dynamometry data from five participants were excluded from the analyses. This included data from all isotonic contractions of two participants from both groups due to incorrect task execution during either pre- or post-measurements (e.g. incomplete range of motion). Isotonic contractions at 60% pT of one participant from the CONTROL group were removed, because the participant was unable to move the lever

Table 2
Participant characteristics of the STEEP and CONTROL group, mean difference (95% confidence interval; CI), significance of difference and effect sizes at baseline.

	STEEP	CONTROL	Mean difference (95% CI)	*p*	Effect size (Cohen's *d*)
Age (y)	69 ± 4	69 ± 4	0.03 (−2.33 to 2.39)	0.98	0.02
Body mass (kg)	72 ± 14	66 ± 11	6.67 (−0.34 to 13.68)	0.06	0.51
Height (cm)	164 ± 6	162 ± 5	2.52 (−0.88 to 5.91)	0.14	0.36
BMI (kg/m^2)	26.77 ± 4.70	25.09 ± 3.36	1.79 (−0.67 to 4.25)	0.15	0.41
Leisure time PA-score	24.52 ± 24.81	22.80 ± 14.53	1.26 (−11.00 to 13.51)	0.84	0.08
Handgrip strength (kg)	28.22 ± 4.77	29.00 ± 5.71	−0.53 (−3.76 to 2.69)	0.74	0.15
Left/Right dominance	1/23	1/20			

arm at this resistance. Significant main effects were found with improvements in the STEEP group, compared to the CONTROL group, for $pT_{isom120}$, pT_{isom90}, pP at 20%, 40%, and 60% of pT_{isom90}, and RVD during unloaded isotonic contraction ($p \leq .01$ for within-group effects in STEEP; Table 3). No improvements were found for pV at any of the applied resistances in either group ($p > .05$).

3.4. Functional and balance performance

SPPB scores were all above 9, indicating that none of the participants showed impaired functional ability. The SPPB scores improved significantly in the STEEP group compared to the CONTROL group ($p = .004$ within-group effect in STEEP; Table 3). However, this change

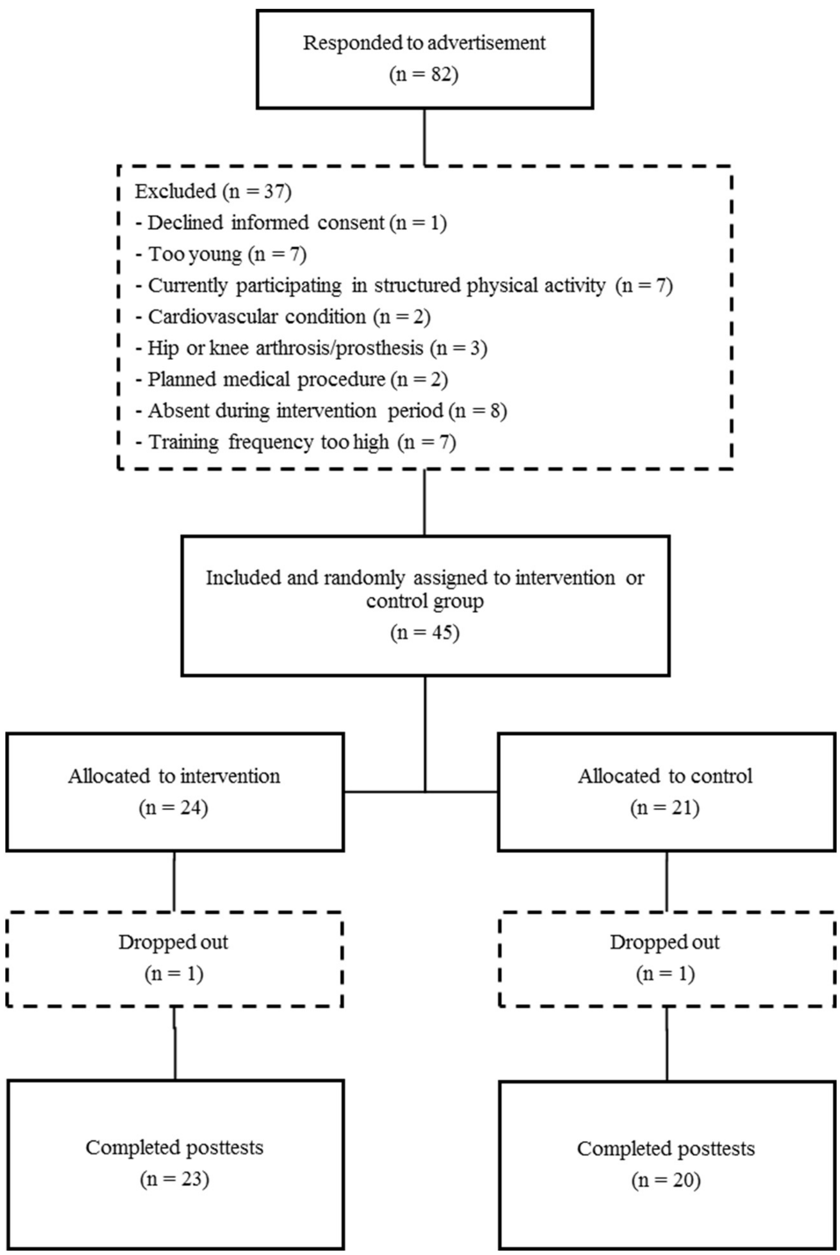

Fig. 2. CONSORT diagram.

Table 3
Mean and standard deviation of muscle volume and force-velocity characteristics of the knee extensors pre- and post-intervention with % change, mean difference (95% confidence interval; CI), significance of difference and effect sizes.

		STEEP	%Δ	CONTROL	%Δ	Between-group difference (95% CI)	Between-group difference for change over time[a]	
							Significance (p value)	Effect size (η_p^2)
CT-scans								
MV right (cm^3)	Pre	193.0 ± 29.2		202.3 ± 32.7		−4.54		
	Post	199.1 ± 28.1	2.8 ± 4.**	200.1 ± 31.5	−1.0 ± 2.9	(−23.39 to 14.32)	0.002	0.214
MV left (cm^3)	Pre	190.8 ± 31.0		199.8 ± 30.4		−4.13		
	Post	196.7 ± 29.5	2.6 ± 3.9**	197.4 ± 27.7	−1.0 ± 3.8	(−22.61 to 14.35)	0.005	0.181
Isometric tests								
pT at 120° (Nm)[b]	Pre	96.3 ± 21.1		112.4 ± 14.5		−7.45		
	Post	110.0 ± 24.2	15.7 ± 20.7**	108.8 ± 19.1	−2.7 ± 16.1	(−18.93 to 4.04)	0.002	0.204
pT 90° (Nm)	Pre	125.5 ± 27.5		142.2 ± 29.0		−4.96		
	Post	137.2 ± 30.8	9.6 ± 10.7**	130.4 ± 38.1	−7.8 ± 21.1	(−23.11 to 13.19)	0.001	0.227
Isotonic test at 0% load								
pV (°/s)	Pre	365.6 ± 24.8		374.3 ± 17.8		−5.80		
	Post	372.4 ± 16.5	2.4 ± 7.4	375.7 ± 16.4	0.4 ± 1.9	(−16.48 to 4.89)	0.301	0.027
RVD (°/s^2)[b]	Pre	1515.4 ± 396.7		1548.4 ± 279.1		46.95		
	Post	1704.4 ± 284.3	18.3 ± 30.1**	1577.6 ± 270.0	2.9 ± 14.3	(−142.18 to 236.08)	0.037	0.109
pP (Nm/s)	Pre	6.4 ± 0.4		6.5 ± 0.3		−0.10		
	Post	6.5 ± 0.3	2.4 ± 7.4	6.6 ± 0.3	0.4 ± 1.9	(−0.29 to 0.09)	0.299	0.027
Isotonic test at 20% load								
pV (°/s)	Pre	304.2 ± 21.5		303.1 ± 18.4		0.79		
	Post	307.1 ± 19.5	1.4 ± 6.0	307.3 ± 23.7	1.4 ± 5.1	(−11.18 to 12.76)	0.888	0.001
RVD (°/s^2)	Pre	1127.1 ± 238.9		1172.5 ± 139.6		−14.69		
	Post	1198.2 ± 167.6	7.7 ± 18.5	1179.9 ± 186.0	0.5 ± 9.0	(−124.29 to 94.91)	0.277	0.030
pP (Nm/s)	Pre	128.1 ± 28.2		143.4 ± 30.6		−7.52		
	Post	140.3 ± 31.3	11.2 ± 12.4**	141.3 ± 29.3	−1.1 ± 5.4	(−25.88 to 10.83)	< 0.001	0.345
Isotonic test at 40% load								
pV (°/s)[b]	Pre	213.6 ± 27.8		206.2 ± 27.7		6.44		
	Post	216.7 ± 36.5	3.8 ± 12.3	215.3 ± 35.6	4.5 ± 11.6	(−11.21 to 24.10)	0.864	0.001
RVD (°/s^2)	Pre	811.4 ± 165.7		810.9 ± 123.9		−3.58		
	Post	853.5 ± 95.6	9.6 ± 28.1	861.2 ± 146.4	6.9 ± 14.6	(−79.63 to 72.48)	0.837	0.001
pP (Nm/s)	Pre	180.6 ± 45.3		193.1 ± 41.6		−6.65		
	Post	195.0 ± 47.6	12.5 ± 14.6**	200.6 ± 40.0	4.5 ± 7.5	(−32.54 to 19.25)	0.045	0.097
Isotonic test at 60% load								
pV (°/s)	Pre	137.8 ± 30.9		127.8 ± 22.6		9.85		
	Post	146.5 ± 30.1	8.2 ± 22.9	131.2 ± 33.3	7.1 ± 19.3	(−6.18 to 25.88)	0.986	< 0.001
RVD (°/s^2)	Pre	547.5 ± 203.8		500.4 ± 180.1		26.41		
	Post	569.1 ± 142.4	18.3 ± 45.9	553.0 ± 209.2	18.8 ± 67.1	(−82.29 to 135.11)	0.662	0.005
pP (Nm/s)[b]	Pre	176.2 ± 54.6		180.9 ± 38.1		3.56		
	Post	200.1 ± 50.3	17.2 ± 23.6**	191.2 ± 50.4	3.6 ± 12.6	(−26.53 to 33.65)	0.029	0.117
Functional performance tests								
SPPB[b]	Pre	11.3 ± 1.0		11.9 ± 0.4		−0.26		
	Post	11.78 ± 0.7	4.6 ± 6.6**	11.8 ± 0.4	−0.8 ± 3.8	(−0.64 to 0.13)	0.002	0.209
5×STS (s)[b]	Pre	11.0 ± 2.4		10.4 ± 1.3		−0.03		
	Post	9.8 ± 2.4	−9.4 ± 12.4**	10.3 ± 1.1	−0.2 ± 10.2	(−1.16 to 1.10)	0.007	0.162
10 m walk (s)	Pre	6.3 ± 1.0		5.9 ± 0.7		0.25		
	Post	5.7 ± 0.9	−9.1 ± 11.3**	5.7 ± 0.9	−4.5 ± 7.6	(−0.27 to 0.77)	0.038	0.100
Stair ascent (s)[b]	Pre	5.0 ± 1.0		4.3 ± 0.9		0.45		
	Post	4.6 ± 0.9	−7.9 ± 9.9**	4.4 ± 1.0	1.9 ± 12.2	(−0.12 to 1.03)	0.004	0.182
CMJ (mm)	Pre	115.7 ± 34.8		133.2 ± 23.8		−14.43		
	Post	124.7 ± 30.2	12.0 ± 19.7	136.1 ± 27.3	2.8 ± 13.7	(−32.18 to 3.31)	0.280	0.029

[a] Group-by-time interaction from mixed ANOVA.
[b] Statistical analyses performed using log-transformed data, reported means and mean differences from non-transformed data.
** Significant within-group difference ($p < .01$).

Table 4
Mean ± standard deviation and significance of time effect on scores from the motivation questionnaires.

	Week 1	Week 6	Week 12	p-Value	Effect size (Kendall's W)
Positive feelings related to exercise	8.73 ± 1.12	9.24 ± 0.78	9.35 ± 0.66	0.015*	0.196
Relief	4.55 ± 3.14	4.65 ± 2.77	3.91 ± 2.91	0.099	0.116
Enjoyability	8.32 ± 2.03	7.95 ± 1.91	8.64 ± 1.89	0.850	0.013
Feasibility	7.11 ± 1.70	6.90 ± 7.87	6.73 ± 2.69	0.643	0.028
Effectiveness	6.45 ± 1.96	6.65 ± 1.90	7.05 ± 2.06	0.334	0.067

Scores were rated on a 11-point Likert scale (ranging from 0 = 'Strongly disagree', to 10 = 'Strongly agree'). p-Values and effect size were obtained using Kendall's W test.
* Indicates a significant time effect ($p < .05$).

was less than one point and therefore not clinically meaningful (Bean et al., 2009). A significant group x time interaction effect was found for functional performance. Functional performance improved in the STEEP group, indicated by decreases in 5xSTS duration, 10 MW duration and SA duration ($p < .01$). No differences were found in the CONTROL group ($p > .05$). In contrast, no interaction effects were found between groups for CMJ height or postural sway during any of the balance tests ($p \geq .05$).

3.5. Motivation questionnaires

Scoring on all items indicated a strong positive perception of the training program (scores above 8), with a further significant increase during the training period ($p = .015$; Table 4). The participants indicated to feel slightly relieved after finishing the training sessions (scores below 5), with no changes over time ($p = .099$). For the items comparing STEEP with resistance exercise, scores indicated a more positive perception towards the STEEP program for enjoyability, feasibility and effectiveness (all scores above 5), which showed no change over the course of the program ($p > .05$).

4. Discussion

To our knowledge, this is the first intervention study to assess bench stepping with incremental step heights as a functional training to improve muscle volume, strength and power in older women. Our main finding is that the STEEP program improved functional performance, muscle volume and force/velocity characteristics of the knee extensors. Additionally, reported feelings related to the bench stepping exercises were very positive.

The functional improvements found in our study are in line with a study by Hallage et al. (Hallage et al., 2010). The same study reported improvements in lower body strength even though they employed bench stepping at regular heights only and did not specifically design their program to achieve strength gains, as indicated by the defined target intensity of 50–70% of the heart rate reserve rather than maintaining the threshold of 60% 1-RM (Baggen et al., 2017; Hallage et al., 2010). However, they only estimated overall strength using a chair-stand test. Other functional training studies (including stair climbing) that found improvements in functional performance, and used isokinetic dynamometers to directly measure isometric and dynamic strength, did not find consistent improvements in knee extension or leg press strength (Manini et al., 2007; Donath et al., 2014). This is likely attributable to the sub-optimal training stimulus for hypertrophy and strength gains provided by stepping at regular step heights (Baggen et al., 2017). Initially, some subjects reported light knee pain during the exercises when progressing to step heights exceeding 18 cm. This was likely attributable to altered foot progression angles indicating toe-out during step ascent, increasing the knee adduction moment (Guo et al., 2007). This was remedied by providing instructions on correct (straight) foot placement.

Our expectation that training with step heights exceeding those regularly encountered in daily life causes improvements in muscle volume, strength and power of the knee extensors was confirmed. Muscle volume increased 2.8% in the STEEP group, comparable to improvements of 3.2% after 12 weeks of high-intensity resistance exercise (80% 1-RM) in a cohort of older men and women (Van Roie et al., 2013). Although improvements in muscle volume are usually correlated with improvements in muscle strength, no causal relationship has been established in previous studies (Dankel et al., 2018). Nevertheless, improvements in muscle volume can be indicative of the number of muscle fibers in parallel and the presence of larger and more powerful type II muscle fibers (Leenders et al., 2013; Narici et al., 2003), providing a buffer against further age-related decreases in strength. Increased muscle volume also acts as a buffer for increased amino acid demands imposed by injuries and disease and is inversely associated with insulin resistance (Wolfe, 2006; Srikanthan and Karlamangla, 2011).

Muscle strength is a good predictor of functional ability and falls and previous research has shown that improvements in muscle strength of the lower limbs decreases the risk of falling by improving moment generation after tripping (Pijnappels et al., 2008a; Granacher et al., 2008; Pijnappels et al., 2008b). The knee extensor muscles in particular play a crucial role during dynamic tasks such as walking, stair negotiation, rising from a chair, and balance control (MacRae et al., 1992; Hughes et al., 1996; Tiedemann et al., 2007; DeVita and Hortobagyi, 2000; McFadyen and Winter, 1988). The average relative increase of muscle strength in the STEEP group (15.7% for $pT_{isom120}$ and 9.6% for pT_{isom90}) appeared to be higher than previously reported improvements with resistance exercise (11.8% and 5.5% respectively), and showed consistent and large effect sizes (Cohen's d; 0.92 for $pT_{isom120}$ and 0.90 for pT_{isom90} versus a very large effect size of 1.60 for $pT_{isom120}$ and a small effect size of 0.45 for pT_{isom90} found by Van Roie et al.) (Van Roie et al., 2013; Dankel and Loenneke, 2018). However, we have to note that the study by Van Roie et al. included both male and female participants, which might have led to higher variability in isometric strength performance, consequently reducing the effect size.

pP, which may be an even stronger predictor of functional ability and falls than strength (de Vos et al., 2005; Bean et al., 2003), was significantly improved in the STEEP group, while pV was not. This indicates that the improvements in pP are mainly attributable to improvements of the force produced, rather than the velocity attained. As with resistance exercise, the improvements of strength and power found in this study are most likely mediated by both muscular and neural adaptations (Manini et al., 2007; Leenders et al., 2013; Narici et al., 2003; Fisher et al., 2016). The lack of improvement of pV is not surprising since the STEEP program did not incorporate explosive or ballistic contractions (de Vos et al., 2005). However, it is worth noting that pV was maintained in the STEEP group despite an increase of the absolute external resistance between the pre- and post-tests (applied relative external load was based on pT_{isom90} obtained during the same session). This indicates that the ability to generate force was improved without decreasing contraction speed, which is confirmed by the fact that RVD did not change in the loaded conditions. Additionally, the improvement in RVD during unloaded contractions indicates that potential improvements in RVD in the loaded conditions may have been negated by the increased absolute load during the isotonic contractions. Remarkably, the gains in power in the STEEP group were not reflected by a significant gain in CMJ height compared to the control group, even though previous research has shown a strong correlation between these outcome measures (Markovic et al., 2004). However, closer inspection of the data revealed that the STEEP group did show an average increase of 12% in CMJ height as opposed to 2.8% in the CONTROL group. The absence of statistical significance could be attributed to the presence of two outliers; one participant in the STEEP group showed a reduced CMJ height of −32.9% whereas one participant in the CONTROL group showed an increase of 41.7%. Although these relative differences were large compared to the standard deviations, we took a conservative approach by not removing them from the analyses because performance of both participants was found to be consistent within all three trials for both pre- and post-tests. However, removing the data from these subjects did result in a significant group x time interaction effect ($p = .007$), indicating a significant improvement in the STEEP group compared to the CONTROL group. The results of the CMJ may also have been affected by a difference in baseline performance between groups, which was bigger than the change score within the training group. To control for this, we performed an additional analysis of covariance (ANCOVA) on the change scores using the baseline as a covariate (data not shown) (Vickers and Altman, 2001). However, these analyses showed similar results to the two-way ANOVA.

Stepping in lateral direction was incorporated to improve balance performance. Previous research has shown that, given the appropriate step height, lateral stepping elicits similar EMG amplitudes in the gluteus medius as hip abduction exercises at intensities recommended by the American College of Sports Medicine to improve muscle volume and strength (Baggen et al., 2017; American College of Sports Medicine, 2017), and that there is a relationship between rate of force development of gluteus medius and mediolateral stability in older adults (Orr et al., 2008). However, in contrast with the improvements found in muscle volume, strength and power, postural sway during the balance tasks of the SPPB was not improved. This lack of improvement in balance performance is likely attributable to the fact that balance performance at baseline was already high (indicated by high SPPB scores), causing a ceiling effect. Consequently, more challenging balance tasks might be needed to reveal training-induced improvements in balance performance and fall recovery (Cofré Lizama et al., 2014).

Motivation questionnaires were administered to provide an indication on the likelihood of long-term training adherence and possible motivational thresholds. The high scores on feelings related to the exercises (items 1–5 of the questionnaire) indicate that the STEEP program did not present any motivational thresholds for training participation in this cohort, which is confirmed by higher adherence compared to previous studies (Farrance et al., 2016), and the low dropout rate. Most of the participants indicated that they had never participated in resistance training and did not intend to in the future. This meant that they could not judge differences in enjoyability, intensity and effectiveness (items 6–8 of the questionnaire) based on prior experience and might have an unfounded negative predisposition towards resistance exercise. Thus, caution should be taken when interpreting the results from these items. Nevertheless, we included these items to provide some indication about the likelihood that bench stepping, even at higher step increments, would suffer from evasion rates that are comparable to those reported for machine-based resistance exercise (Martins et al., 2013). We also need to take into account that these positive scores could be affected by self-selection and social desirability (Van Roie et al., 2015). Regardless, this still provides a good indication of possible subjective thresholds. Combined with the previously reported high long-term adherence rates of group-based training (Farrance et al., 2016), low costs and high accessibility of bench stepping, these results indicate a high likelihood of long-term training adherence to the STEEP program.

Finally, we have to acknowledge some limitations of this study. First, although the training-based improvements in muscle volume, strength and power found in this study appear to be considerable, it is difficult to define their clinical impact. For example, this is possible for the SPPB, because it is specifically designed as a tool to detect (risk of) disability with clearly defined cut-off points for diagnostic purposes. However, if we compare the improvements found with the expected relative losses associated with a sedentary lifestyle in older adults, 12 weeks of bench-stepping with incremental heights would compensate for an annual loss of muscle volume (1–2%) (von Haehling et al., 2010). Furthermore, the improvements in strength and power far exceed their estimated annual losses of 3% (Baumgartner et al., 1998) and 3–4% (Narici and Maffulli, 2010) respectively.

Second, the results of this study cannot be generalized to frail older adults. Our primary aim was to investigate whether the STEEP program could be implemented as an effective prevention training program for older women who are not yet at risk. However, the significant improvements found indicate that it may be worthwhile to explore the feasibility and effectiveness of the STEEP program in frail older adults with an increased risk of falls or loss of mobility. Safely elevating the center of mass with single leg support may be challenging or unsafe for these populations. However, safety bars (Salem et al., 2004; Baggen et al., 2017) and adjustments of training progression to ensure individual maximum functional capacity is not exceeded, can make bench stepping a safe and suitable exercise modality for frail older adults.

In conclusion, this study showed that bench stepping, with incremental step heights in both forward and lateral direction, improves functional performance but also increases muscle volume, strength and power of the knee extensors. By simultaneously modifying multiple risk factors for falls and functional decline, the STEEP program provides an effective, time-efficient and low-threshold exercise program for older women.

Conflict of interest

The authors have no conflicts of interest to declare.

Acknowledgements

This work was supported by the European Commission through MOVE-AGE, an Erasmus Mundus Joint Doctorate programme (grant number 2014-0691); and the Fund for Scientific Research Flanders (FWO-Vlaanderen, grant number G0521-05). The authors would like to thank all participants, the instructor and the student assistants involved in this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.exger.2019.02.013.

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