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Year: 2017

Version:

Please cite the original version:

Turpela, M., Häkkinen, 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. https://doi.org/10.1016/j.exger.2017.08.013

Effects of different strength training frequencies on maximum strength, body composition and functional capacity in healthy older individuals

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ABSTRACT

There is controversy in the literature regarding the dose-response relationship of strength training in healthy older participants. The present study determined training frequency effects on maximum strength, muscle mass and functional capacity over 6 months following an initial 3-month preparatory strength training period. One-hundred and six 64-75 year old volunteers were randomly assigned to one of four groups; performing strength training one (EX1), two (EX2), or three (EX3) times per week and a non-training control (CON) group. Whole-body strength training was performed using 2–5 sets and 4–12 repetitions per exercise and 7–9 exercises per session. Before and after the intervention, maximum dynamic leg press (1-RM) and isometric knee extensor and plantarflexor strength, body composition and quadriceps cross-sectional area, as well as functional capacity (maximum 7.5m forward and backward walking speed, timed-up-and-go test, loaded 10-stair climb test) were measured. All experimental groups increased leg press 1-RM more than CON (EX1: 3±8%, EX2: 6±6%, EX3: 10±8%, CON: -3±6%, $P<0.05$) and EX3 improved more than EX1 ($P=0.007$) at month 9. Compared to CON, EX3 improved in backward walk ($P=0.047$) and EX1 in timed-up-and-go ($P=0.029$) tests. No significant changes occurred in body composition. The present study found no evidence that higher training frequency would induce greater benefit to maximum walking speed (i.e. functional capacity) despite a clear dose-response in dynamic 1-RM strength, at least when predominantly using machine weight-training. It appears that beneficial functional capacity improvements can be achieved through low frequency training (i.e. 1–2 times per week) in previously untrained healthy older participants.

Keywords: walking; timed-up-and-go; stair climb; muscle mass; aged men and women; resistance exercise; lower limbs

1 INTRODUCTION

Strength training is a widely used method to combat the deleterious effects of aging and age-related reduced physical activity on maximum strength, muscle mass and functional capacity. There are many combinations of acute program variables (identified by Kraemer and Ratamess 2004) that can influence the overall outcome of a strength-training program. These variables are; the choice of exercise(s) and exercise order, number of sets/repetitions, inter-set and inter-exercise rest interval, and the intensity of each exercise. The effects of several of these variables on maximum strength and muscle mass development have been examined over previous decades (e.g. Campos et al. 2002; Moss et al. 1997). But one variable, training frequency, has received little attention (Steib et al. 2010). It is important to be clear that training frequency in the present study is limited to whole-body strength training (rather than split programs; training one specific muscle group per day) and the vast majority of studies using training 2-3 times per week does not allow reviews/meta-analyses to accurately determine the effects of different frequencies on outcome variables.

Nevertheless, physical activity guidelines from bodies such as the World Health Organization and the American College of Sports Medicine recommend whole-body strength training for healthy individuals above 65 years at a frequency of *at least* two times per week (Ratamess et al. 2009; World Health Organization 2010). This is despite the little experimental evidence to support such a recommendation regarding development of maximum strength or muscle mass, and particularly functional capacity, in previously untrained healthy older individuals.

This is in contrast to the quite well-established evidence base to recommend progressive loading and volume to promote achieving these desirable outcomes (Ratamess et al. 2009).

A seminal paper investigating training frequency (one versus two versus three times per week) on improvements in maximum strength and functional capacity observed no difference in improvements between groups (Taaffe et al. 1999). Also, a recent meta-analysis showed no evidence of different strength improvements comparing frequencies of one, two or three times per week (Silva et al. 2014). Maintenance of muscle mass is another important consideration for older adults given its role in force production and also metabolic regulation. However, to our knowledge, no study has investigated the effect of training frequency on muscle hypertrophy in healthy older individuals. The effect of training frequency on muscle hypertrophy would be pertinent to examine since most studies use either two or three times per week, which has been shown to exert little difference (Wernbom et al. 2007), but recent evidence suggests these frequencies are more beneficial than one time per week (Schoenfeld et al. 2016), which does support the physical activity guidelines.

One important methodological consideration when evaluating these studies is the existing training status of the participants. All four original articles that we identified in the literature investigating training frequency in healthy older individuals used previously untrained participants (DiFrancisco-Donoghue et al. 2007; Farinetti et al. 2013; Padhila et al. 2015; Taaffe et al. 1999). As it is known that untrained individuals respond more robustly to a variety training protocols, the use of completely untrained participants may reduce any potential to identify differences in adaptive responses in response to different training frequencies.

Therefore, there is a need to further study the influence of training frequency on improvements in maximum strength, muscle mass and functional capacity in healthy older individuals that have undergone (some) strength training prior to separation into different training frequencies. Consequently, the purpose of the present study was to determine whether training frequency affects improvements in maximum strength, muscle mass and functional capacity over a 6-month period following an initial 3-month low-intensity preparatory strength training period.

2 MATERIALS AND METHODS

2.1 Participant recruitment and randomization

This study was the second arm of a randomized controlled trial (NCT02413112). Participants were 64–75-year-old men and women. Exclusion criteria were; (1) regular aerobic exercise (>180 min·week^{-1}), 2) any previous strength training experience, (3) Body Mass Index >37, (4) serious cardiovascular disease or lower limb injuries/disease that may lead to complications during exercise or affect the ability to perform testing and training, (5) use of walking aids, (6) use of medication that affect the neuromuscular or endocrine systems, (7) previous testosterone-altering treatment, and (8) smoking. Therefore, participants were otherwise healthy apart from conditions such as Type II diabetes, high blood pressure, and/or high cholesterol in several cases, were not frail or obese, were not engaged in systematic fitness training, and were able to perform strength training with no restrictions. While the participants did not engage in aerobic exercise, it was clear from the pre-study interviews that typical 'Nordic' low-intensity physical activity (e.g. berry-picking, gardening, forestry etc.) was part of their lifestyle – and may, in part, explain their largely healthy condition despite not meeting recommended levels of physical activity (WHO 2010).

The recruitment process and exclusion of participants in shown in Figure 1. Prior to physician assessment, advertisement letters were posted to 2000 65–75-year-old men and women in the Jyväskylä region and potential participants registered to the study by completing an online researcher-designed questionnaire (n=454). As part of the registration questionnaire, potential participants were asked about their current and previous level of physical activity, medical history including any current/ongoing/permanent conditions, current and previous medications and also immediate family medical history. The participants were blind to the purpose of these questions (i.e. to assess eligibility). After assessing the eligibility of the registered individuals for lower limb injuries, skeletomuscular diseases and physical activity levels, potential participants were invited to an information session (n=148). Each participant was carefully informed of the study design and potential risks before the study, after which they provided written consent and attended a physician’s examination (n=116). During the physician’s examination, potential participants were interviewed by the researchers to ensure that they were eligible to be included to the study. After baseline testing, the participants (n=106) were allocated an identification number and a computer-generated random number sequencer was used to allocate each participant into one of four groups (Figure 1); training one (EX1), two (EX2), three (EX3) times per week and non-training/wait control (CON).

During the study, one participant dropped out due to back pain induced by the strength testing in month 3, one participant dropped out due to re-occurrence of heart arrhythmia and one participant dropped out due to stress-related illness. Six participants failed to attend at least 90% of the assigned training sessions for their group and were consequently removed from the analyses (as noted in Figure 1). Furthermore, after data checking, several participants’ electromyography and voluntary activation level data were excluded from final analysis due to technical faults. The study was conducted according to the Declaration of Helsinki and was approved by the ethical committee of the University of Jyväskylä, Finland. Baseline characteristics of the participants in each group are shown in Table 1, with the only differences observed between men and women in height and body mass.

Some participants were taking medication during the study that was deemed not to interfere with their ability to participate in training or testing. The total number users of each type of medication are listed here; EX1: cholesterol medication (3 men + 3 women), blood pressure medication (4 men + 3 women), blood glucose medication (1 men + 1 women), thyroid medication (1 men + 2 women), beta-blockers (1 woman); EX2: cholesterol medication (2 men + 3 women), blood pressure medication (5 men + 6 women), blood glucose medication (2 women), thyroid medication (1 man + 2 women), beta-blockers (1 man + 1 woman); EX3: cholesterol medication (1 man + 3 women), blood pressure medication (5 men + 5 women), blood glucose medication (2 men), thyroid medication (1 man + 4 women), beta-blockers (1 man + 2 women); CON: cholesterol medication (2 men + 2 women), blood pressure medication (4 men + 3 women), beta-blockers (1 man + 1 woman).

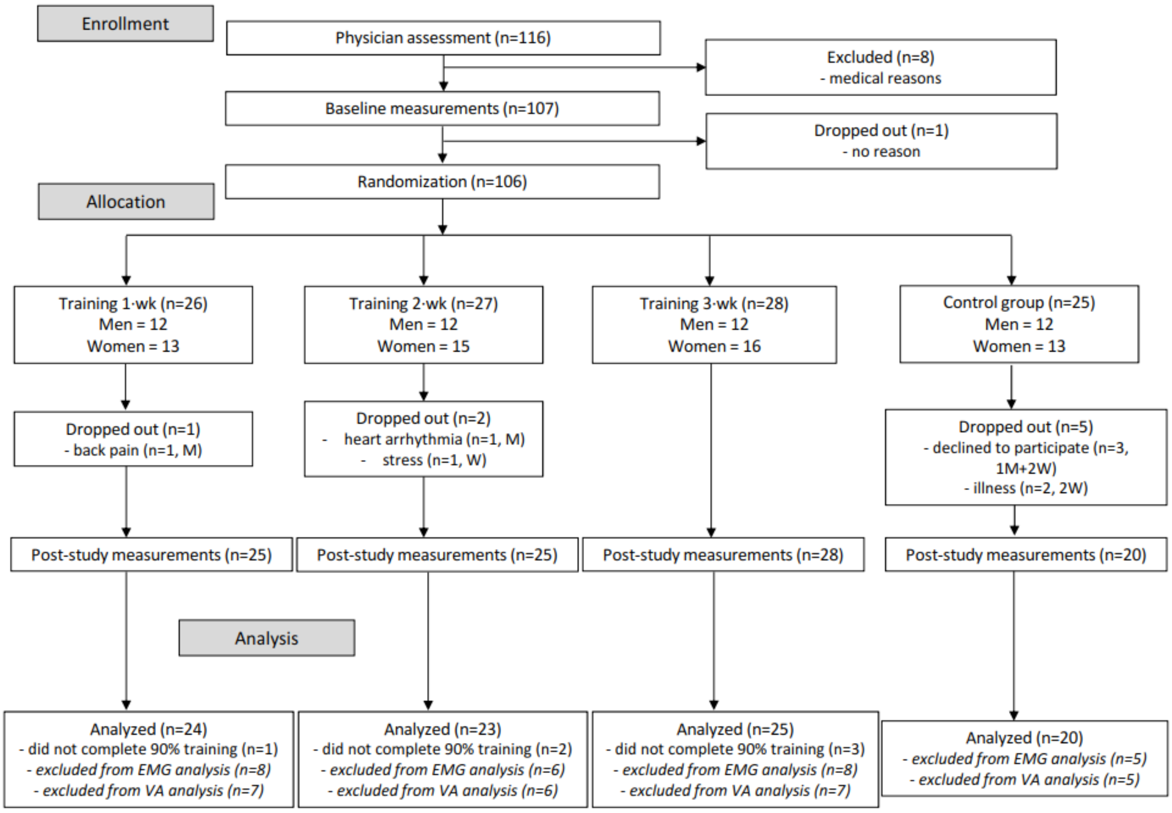

Fig.1. Study flowchart from the point of physician assessment. M = men, W = women, EMG = electromyography, VA = voluntary activation level.

Table 1. Participant characteristics and performance at baseline (mean±SD).

	EX1	EX2	EX3	Control
Sex (M/W)	11/13	9/14	11/14	11/9
Age (years)	70 ± 3	69 ± 3	70 ± 3	69 ± 2
Body mass (kg)	76 ± 15	81 ± 15	82 ± 16	74 ± 11
Height (m)	1.67 ± 0.09	1.68 ± 0.07	1.67 ± 0.10	1.68 ± 0.09
Body mass index (kg/m^2)	27 ± 3	29 ± 5	29 ± 4	26 ± 3
Fat mass (kg)	25.9 ± 6.4	29.1 ± 9.3	28.3 ± 8.1	22.5 ± 6.5*
Fat-free mass (kg)	47.0 ± 11.9	47.9 ± 10.6	48.7 ± 10.6	48.5 ± 10.1
1-RM load (kg)	104.0 ± 34.7	115.4 ± 36.5	111.6 ± 37.0	119.5 ± 29.7
KE MVC (Nm)	153 ± 57	155 ± 49	147 ± 44	157 ± 45
PF MVC (Nm)	158 ± 61	159 ± 44	160 ± 40	160 ± 44
Forward walk (s)	3.1 ± 0.5	2.9 ± 0.6	3.0 ± 0.5	2.7 ± 0.4
Backward walk (s)	4.3 ± 1.2	4.2 ± 1.5	4.5 ± 1.4	3.7 ± 0.8
TUG (s)	9.4 ± 1.5	9.3 ± 1.7	9.4 ± 1.3	8.6 ± 0.8
Stair climb (s)	3.5 ± 0.9	3.4 ± 0.7	3.5 ± 0.7	3.1 ± 0.4

M = men, W = women, 1-RM = one-repetition maximum, KE MVC = maximum isometric knee extension torque, PF MVC = maximum isometric plantarflexion torque, TUG = timed-up-and-go. * = P=0.039 between Control and EX2.

2.2 Dynamic leg press performance

Concentric bilateral leg press one-repetition maximum (1-RM) load (kg) was used to assess maximum dynamic strength (David Sports Ltd, Helsinki, Finland). Briefly, following warm-up, single repetitions with increments of 5kg were performed until the participants could no longer fully extend their hips and legs (full extension = 180°). Each trial was separated by 1.5 min. All data were relayed to a pc via an AD converter (Micro 1401, Cambridge Electronic Design, UK) and recorded using Signal 4.04 software (Cambridge Electronic Design, UK). Data was sampled at 2000Hz and filtered by a 10-Hz low-pass filter (fourth-order Butterworth) and the best trial was used in further analyses.

2.3 Isometric knee extension and plantarflexion performance

Maximum unilateral isometric knee extension torque of the right leg was measured using a custom-built isometric force chair. Inelastic straps were used to secure the participant with both hip and knee angles of 110°. Participants were instructed to kick “as fast and as hard as possible” and maintain their maximum force for approximately 3s. The force signal was sampled as described in the leg press trials with the highest force used in further analysis. Three trials were performed with a fourth trial performed if improvements were more than 5%. Thereafter, two additional maximum isometric knee extension trials were performed with femoral nerve stimulation delivered during the force plateau and 2s after contraction cessation following similar procedures as Walker et al. (2014). Rectangular pulses (400V) of 200μs were delivered by a constant current stimulator (Model DS7AH, Digitimer Ltd, UK) to the femoral nerve of the right leg through 5cm^2 self-adhesive electrodes (Polar Trode, Niva Medical Ltd, Espoo, Finland) placed in the femoral triangle either side of the nerve, which was identified by palpating and identifying the femoral artery. Current intensity was gradually increased until no further increases were observed in peak-to-peak M-wave amplitude of VL and VM. To ensure maximal activation, an additional 20% current was used during subsequent stimulations. Single twitches were delivered in a resting condition to determine peak-to-peak maximum M-wave amplitude. Single twitches were also delivered about the maximum torque during isometric knee extension trials and 2s after contraction cessation to determine voluntary activation level according to Merton’s (1954) interpolated twitch technique. Maximum force was measured and then converted to torque by taking into account the lever arm distance from the knee joint-center to the strain gauge.

Maximum bilateral isometric plantarflexion torque was assessed in a seated position by a custom-built plantarflexion device with knees flexed to approximately 90° using similar methods to Unhjem et al. (2015). The balls of the feet were positioned on a shelf connected to the strain gauge (90° ankle joint-angle) and the knees were held in-place by a cushioned board. Participants performed 3-4 isometric plantarflexion actions following the same instructions as for the knee extension trials. Maximum force was measured and then converted to torque by taking into account the lever arm distance from the ankle joint-center to the strain gauge.

2.4 Functional capacity

Four maximal walking tests performed were included in the assessment of functional capacity; (1) 7.5m forward walk, (2) 7.5m backward walk, (3) Timed Up-and-Go test (TUG), and (4) loaded 10-stair climb test. Participants were instructed to perform the tests "as fast as possible without compromising safety". Each test was recorded by photocells except TUG, which used a contact mat positioned under the chair to determine rise from and return to the chair. The participants were not allowed to use their arms to assist in the chair rise or return. During the 10-stair climb test, the participants carried one bag of 5kg (women) or 10kg (men) and were instructed to maintain and extended elbow position and prevent arm-swinging during the ascent (Figure 2). The best performance from two acceptable trials was used in the analyses, and the sum result from both directions was used for TUG.

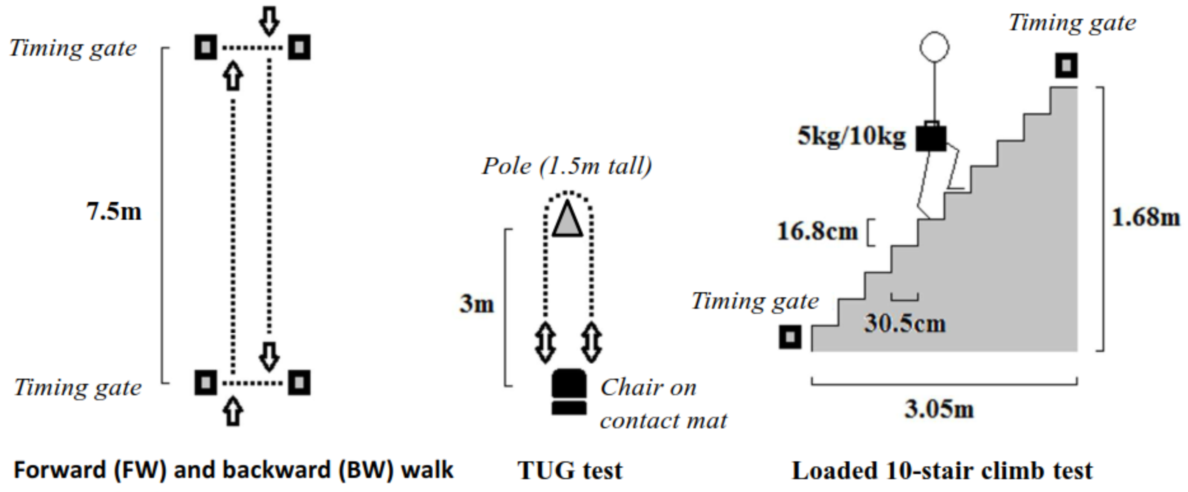

Fig.2. Experimental set-up and procedures for the functional capacity tests. TUG = timed-up-and-go.

2.5 Quadriceps electromyography measurement and analysis

Electrode locations for electromyography (EMG) recordings were marked by indelible ink tattoo to allow accurate replacement during all test sessions. Bipolar Ag/AgCl electrodes (5mm diameter, 20mm inter-electrode distance, common mode rejection ratio >100dB, input impedance > 100MΩ, baseline noise <1µV rms) were positioned following shaving and skin abrasion on the vastus lateralis (VL) and medialis (VM) of the right leg according to SENIAM guidelines. Raw EMG signals were sampled at 2000Hz and amplified at a gain of 500 (sampling bandwidth 10-500Hz). Raw signals were sent from a hip-mounted pack to a receiving box (Telemyo 2400R, Noraxon, Scottsdale, USA), then were relayed to an AD converter (Micro1401, Cambridge Electronic Design, UK) and recorded by Signal 4.04 software (Cambridge Electronic Design, UK). Offline, EMG signals were band-pass filtered at 20-350Hz and root mean square was obtained from approx. 65° to full leg extension (i.e.

180°) during 1-RM trials with values from VL and VM averaged (VL+VM/2) from the best trial and used in further analysis.

2.6 Body composition

Participants fasted overnight for 12 hours and were instructed to drink 0.5 liters of water 1 hour before measurements. After determination of height by a fixed wall-mounted scale, participants underwent full body scanning by dual-energy X-ray absorptiometry (DXA) in minimal clothing (LUNAR Prodigy Advance with encore software version 9.3, GE medical systems, USA). The legs were separated by a polystyrene block and secured by inelastic straps about the ankles. Total body fat mass and fat-free mass, as well as fat-free mass of the legs was determined using software-generated analysis.

2.7 Muscle cross-sectional area

Muscle cross-sectional area (CSA) measurements of the right leg were taken 1-2 days prior to dynamic leg press performance tests and 6-7 days after the final training session to account for any exercise-induced swelling. CSA of the vastus lateralis, vastus intermedius, gastrocnemius medialis and lateralis was assessed by B-mode axial-plane ultrasound (model SSD-α10, Aloka Co Ltd, Tokyo, Japan) using a 10 MHz linear-array probe (60 mm width) coated with water-soluble transmission gel with the extended-field-of-view mode (23 Hz sampling frequency). This method has been used during several of our training studies (Walker et al. 2014, 2015) and has been shown to be valid (Ahtiainen et al. 2009). Indelible ink tattoos on the medial and lateral sides of the target muscles ensures accurate replacement of scanning track. Oriented in the axial-plane, the probe was moved manually with a slow and continuous movement from medial to lateral along a marked line on the skin. Great care was taken to diminish compression of the muscle tissue. Images were obtained throughout the movement. As the orientation of each image relative to adjacent images is known, the software builds a composite image. Four panoramic CSA images were taken at; (1) 50% femur length from the lateral aspect of the distal diaphysis to the greater trochanter and (2) 30% lower limb length from the lateral articular cleft between the femur and tibia condyle to the lateral malleolus following the methods used by Rosenberg et al. (2014). Upon visual inspection of the composite images three were selected to undergo further analysis. CSA was determined by manually tracing along the border of each muscle using Image-J software (version 1.37, National Institute of Health, USA). The mean of the two closest values for each muscle were taken as the CSA result.

2.8 Strength training program

The experimental group performed whole-body strength training either one (EX1), two (EX2) or three (EX3) times per week for 6 months on non-consecutive days and each session was supervised by experienced gym instructors. The 6-month program was divided into two 3-month mesocycles (see supplementary material). All exercises were performed on commercially available weight-stack equipment (Precor Vitality Series^{TM}, Precor Inc, UK) apart from several free-weight exercises in mesocycle 2. The primary goal of mesocycle 1 was to increase maximum strength and muscle mass. The primary goal of mesocycle 2 was to increase maximum strength and muscle activation/power. Intensity for all upper and lower limb exercises was approximately 70–90% 1-RM with power training performed using 30-80% 1-RM loads. Multiple sets (2-5) were performed with repetition ranges of 4-12 and inter-set rest of 1-3min depending on the training goal (loads used during training are depicted in Figure 3). All participants were required to perform at least 1 set to concentric failure (with the exception of power training). All participants were required to complete at least 90% of all allocated training sessions prior to testing. Participants in the non-training control group were instructed to maintain their normal physical activity throughout the study period. All participants recorded their daily leisure-time physical activity levels in diaries throughout the 6-month period and 3-day (including one weekend day) diet diaries were collected during each mesocycle. The recording of physical activity followed procedures of Waller et al. (2013).

2.9 Statistical analyses

All data are presented as means and standard deviations (±SD). All statistical methods were performed using IBM SPSS statistics 24 software. The Kolmogorov-Smirnov test was used to test normality and Levene's test was used to analyze homogeneity of variance. One-way ANOVA was used to assess potential differences at baseline. Repeated measures analysis of variance (ANOVA; 4 group × 2 time) was used to determine significant time and time×group effects of the intervention. Bonferroni post hoc tests used to determine significant differences within-group over time, while one-way ANOVA with Bonferroni post hoc tests were used to determine whether the relative changes (Δ%) over time were different between-groups. Effect sizes (Hedges' *g*) were calculated for the differences in relative change between the experimental and control groups, where small (<0.3), medium (0.3–0.8), and large (>0.8) effect sizes were identified. Pearson's product moment correlation coefficient was used to determine possible relationships between outcome measures. Statistical significance was accepted when $P<0.05$. Reliability for the performance measures between the familiarization session and baseline measures were; 1-RM 0.97 and 5.5%, peak power 0.94 and 11.2%, maximum isometric knee extension force 0.89 and 9.6%, maximum isometric plantarflexion force 0.87 and 9.7%, forward walk 0.82 and 6.3%, backward walk 0.81 and 8.3%, TUG 0.89 and 3.2%, 10-stair climb 0.96 and 3.2%, and CSA 0.94 and 4.2% for Intra-class correlation coefficient (r) and coefficient of variation (%), respectively.

3 RESULTS

3.1 Loads used during the strength training intervention

All training loads used throughout the study are presented in the supplementary material for the leg press, knee extension and chest/bench press exercises. Figure 3 shows the highest loads used during each week for the leg press exercise in all training groups.

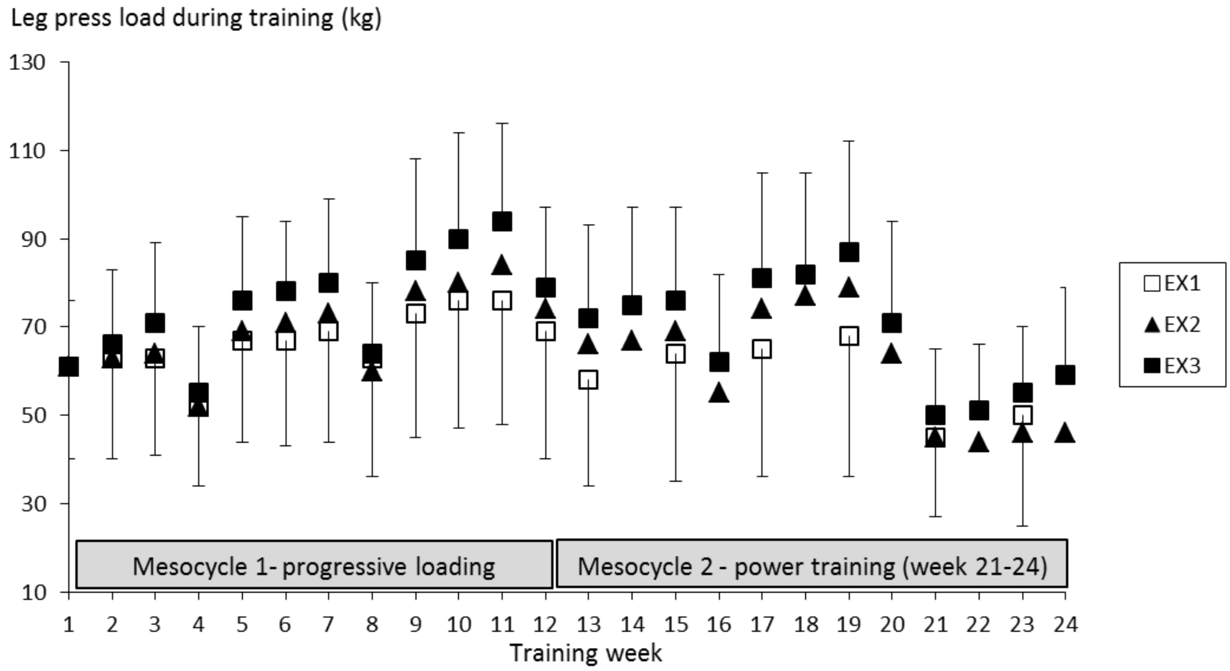

Fig.3. Highest (weekly) load used during the leg press exercise (mean±SD). Every fourth week was used as a ‘tapering week’ with lighter loads used. Progressive resistance training was used during mesocycle 1, which began again at the beginning of mesocycle 2. The last four weeks training was power training using loads of approx. 30–60% 1-RM.

3.2 Neuromuscular performance and muscle activation

Statistically significant main effects for time (F=25.8, P<0.001) and time×group interaction (F=12.7, P<0.001) were observed in leg press 1-RM, where post hoc tests revealed that EX2 (6±6%, P<0.001) and EX3 (10±8%, P<0.001) increased strength significantly over the intervention period. At month 9, between-group differences were observed for all experimental groups versus control and between EX3 and EX1 (P=0.007, 95% confidence interval=1.3 to 12.4%, *g*=0.89). The same results were observed when 1-RM was expressed relative to BM (Figure 4). There were no significant (time×group) main effects for maximum isometric knee extension (Figure 4) or plantarflexion.

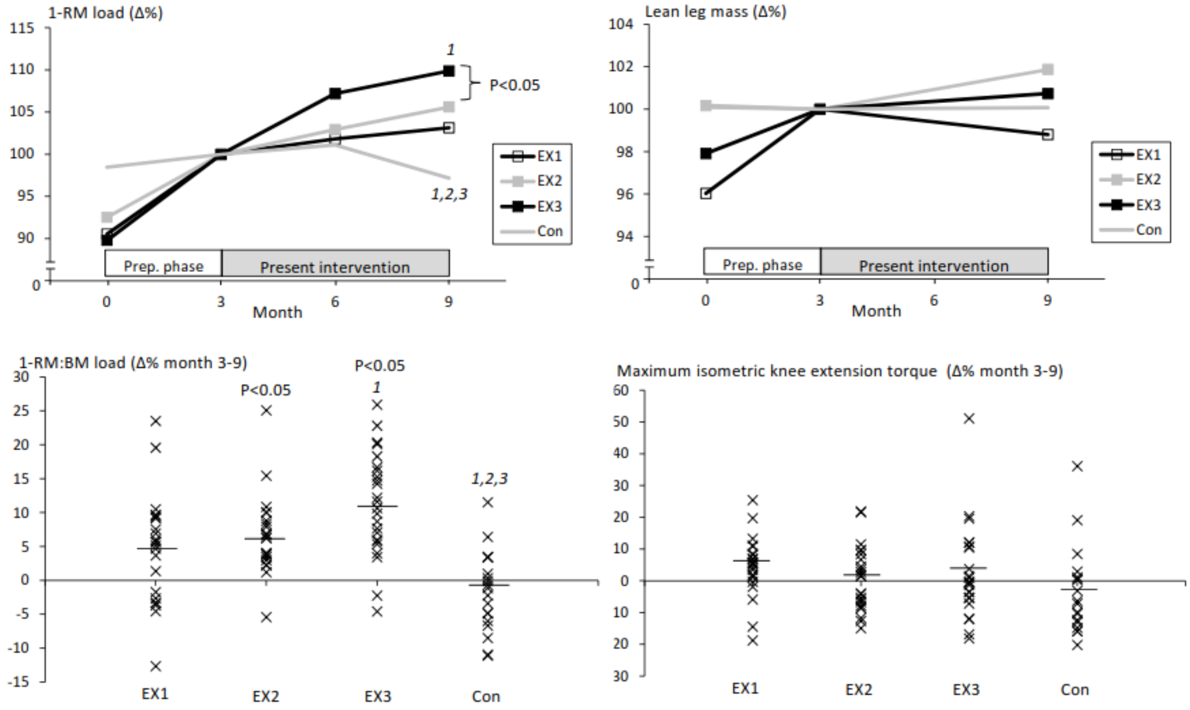

Fig.4. Changes in maximum strength and muscle mass for each group during the study. 1-RM load (top left), lean leg mass (top right), 1-RM normalized to body mass (bottom left), maximum isometric knee extension torque (bottom right). In the bottom panels, each participant's data is marked by an × and the line indicates the group mean. Significant within-group differences are marked with p<0.05, significant between-group differences are

marked above the data points with the number corresponding to the group to which it differs.

Statistically significant main effects for time (F=40.8, P<0.001) and time×group interaction (F=4.4, P=0.007) were observed in muscle activity of the quadriceps (VL+VM/2) during leg press 1-RM, where post hoc tests revealed that all experimental groups increased significantly over the intervention period (EX1: 25±29%, P=0.003; EX2: 31±37%, P=0.002; EX3: 43±31%, P<0.001). Between-group differences were observed for EX3 and control (P=0.005, 95% confidence interval=7.9 to 63.2%, *g*=1.18). However, once normalised to maximum M-wave amplitude there were no significant main effects, and within-group changes were no longer statistically significant. Furthermore, there were no significant main effects for voluntary activation level assessed by the twitch interpolation technique during isometric knee extension trials.

3.3 Functional capacity

Statistically significant main effects for time and trends for time×group interaction were observed for backward walk (F=9.9, P=0.002, and F=2.7, P=0.053, respectively), TUG (F=19.9, P<0.001, and F=2.6, P=0.056, respectively) and loaded 10-stair climb (F=26.8, P<0.001, and F=2.7, P=0.051, respectively). A significant main effect for time (F=35.9, P<0.001) was observed for forward walk. From month 3 to 9, EX1 improved forward walk (-7±8%, P=0.002) and TUG (-4±4%, P<0.001) performance only. EX2 and EX3 improved performance in all functional capacity tests from month 3 to 9; forward walk (EX2: -4±6%, P<0.001; EX3: -5±6%, P=0.001), backward walk (EX2: -4±8%, P=0.02; EX3: -8±9%, P=0.001), TUG (EX2: -2±3%, P=0.011; EX3: -3±6%, P=0.033) and loaded 10-stair climb (EX2: -5±4%, P<0.001; EX3: -

4±5%, P=0.001). At month 9, between-group differences were observed for EX3 and control in backward walk (P=0.047, 95% confidence interval=-19.7 to -0.1%, *g*=0.72, Figure 5) and EX1 versus control in TUG (P=0.029, 95% confidence interval=-8.2 to -0.3%, *g*=0.95, Figure 5).

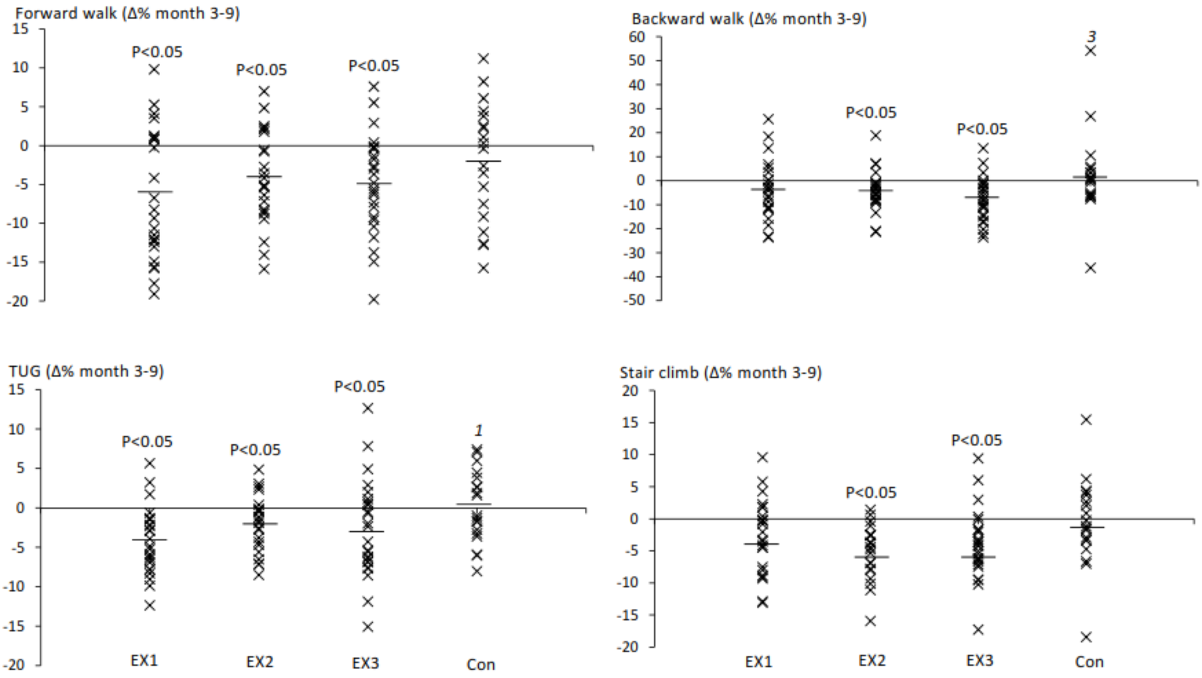

Fig.5. Changes in time to complete all functional capacity tests from month 3 to 9. 7.5m forward walk (top left), 7.5m backward walk (top right), timed-up-and-go test (bottom left), loaded 10-stair climb (bottom right). Each participant's data is marked by an × and the line indicates the group mean. Significant within-group differences are marked with p<0.05, significant between-group differences are marked above the control group's data points with the number corresponding to the experimental group to which it differs.

3.4 Body composition and muscle mass

There were no significant main effects for total fat mass, total lean mass or lean leg mass (Figure 4), or CSA for any muscle assessed.

3.5 Habitual physical activity and nutritional intake

Habitual physical activity external to the prescribed intervention was similar between all groups (average minutes per week = EX1: 136±125, EX2: 121±110, EX3: 108±109, control: 172±69). Walking was the most common mode of physical activity, and this did not differ between groups either in total time or in proportion of total physical activity (EX1: 107±122, EX2: 80±70, EX3: 65±77, control: 122±65 min·week^{-1}; EX1: 69±33, EX2: 70±32, EX3: 60±36, control: 70±26 % of total physical activity).

Results from the 3d diet diaries showed that there were no statistically significant differences between any group for total carbohydrate (EX1: 218±60, EX2: 220±81, EX3: 205±74, control: 213±61 g), protein (EX1: 88±23, EX2: 89±25, EX3: 82±21, control: 86±35 g) or fat (EX1: 75±24, EX2: 77±27, EX3: 84±20, control: 84±43 g) intake or when these totals were normalized to body mass (e.g. protein g·kg^{-1} = EX1: 1.2±0.3, EX2 1.2±0.3, EX3: 1.1±0.2, control: 1.2±0.4).

3.6 Correlation analyses

All neuromuscular performance and functional capacity outcome measure change scores were assessed to determine bivariate correlation. The only variable-pair to demonstrate statistical significance was the change in leg press 1-RM and the change in loaded 10-stair climb from month 3 to 9 (r=-0.22, p=0.036, n=88, Figure 6). There were no relationships between habitual physical activity level and change in neuromuscular performance or functional capacity.

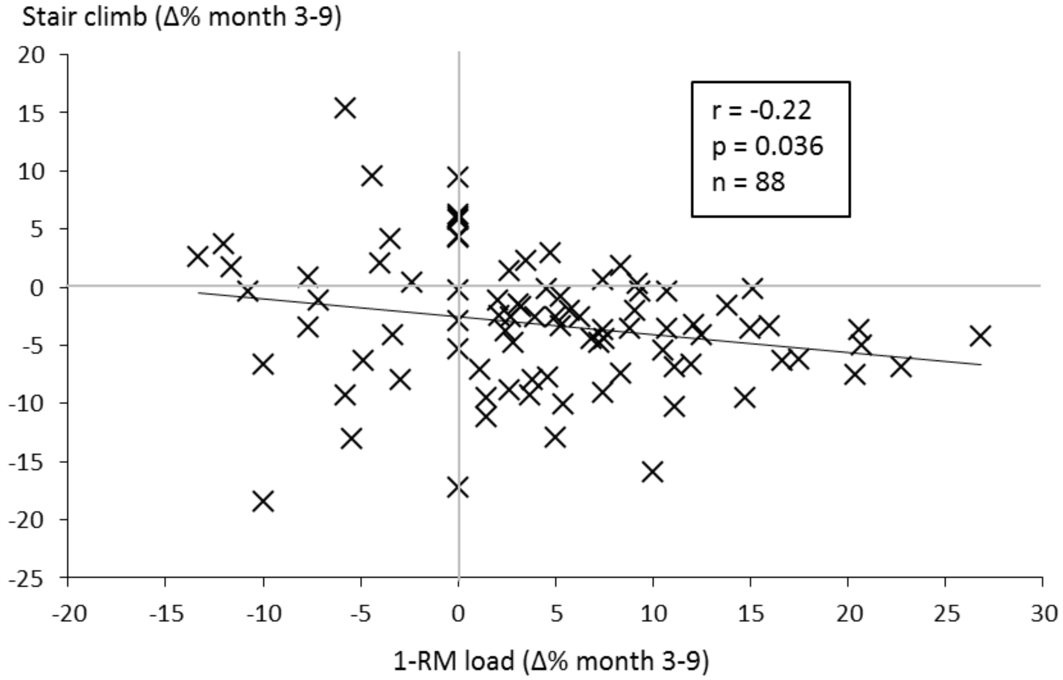

Fig.6. Relationship between the change in 1-RM load (i.e. maximum dynamic strength) and the change in loaded 10-stair climb time from month 3 to 9. Each participant's data is marked by an ×.

4 DISCUSSION

The main findings of the present study were that; 1) training frequency influenced maximum 1-RM gain in a dose-dependent manner but did not result in improved strength as measured by maximum isometric unilateral knee extension or isometric seated plantarflexion torque, 2) all experimental groups improved in some or all tests of functional capacity, but higher training frequency did not provide additional benefit, and 3) the present study did not observe any changes in body composition or muscle mass nor observe differences in muscle activity that might explain possible differences in 1-RM performance.

Taaffe and colleagues (1999) were the first to study the effects of training frequency in older individuals (one versus two versus three times per week). In all 8 exercises included in their study, equivalent improvements were made in 1-RM using a program of 3 sets at 80% of 1-RM for 24 weeks. Furthermore, equivalent improvements were made in a chair sit-to-stand test, while improvements in a 6m backward walking test (that approached statistical significance) also displayed no between-group differences. The results of the present study are in contrast to those of Taaffe et al. (1999) for 1-RM development but are similar regarding functional capacity tests. One factor for the conflicting 1-RM data may have been that the participants in the present study had undergone a 3-month preparatory strength training period where 1-RM had already increased approximately 12% (unpublished data), and so this would reduce the potential for further improvement in EX1 and EX2. Interestingly, reducing training frequency from two to one time per week did not adversely affect the gain in 1-RM strength in older women (Walker et al. 2017). When investigating maximum strength only, DiFrancisco-Donoghue et al. (2007) did not observe different 1-RM gain when training with a frequency of one or two times per week and, with the exception of the chest press exercise, Padhila et al. (2015) did not observe differences in 1-RM gain with two or three times per week. Therefore, it seems that there is potential little difference between training frequencies in the magnitude of maximum strength gain over the first few months of initiating strength training in older people.

The only study that we are aware of to show clear differences between training frequencies was a study by Farinetti et al. (2013). Using a training-specific (but not maximum strength test *per se*) a dose-response was observed for 10-RM improvement in the knee extension and bicep curl exercises (3x > 2x > 1x) but not for the bench press or calf raise. While TUG performance was not influenced by training frequency, chair sit-to-stand and 2m walking speed improved more after two and three times compared to one time per week (Farinetti et al. 2013). In comparison with the present study's results, the (shorter distance) 2m walking speed test was in contrast but the TUG data were similar.

Overall, studies that have investigated the effect of training frequency on strength improvement have produced conflicting results and we are unable to determine a definitive conclusion. The majority of findings suggest that simply the initiation of strength training itself is the main factor for improved functional capacity, rather than any single program design variable. Also, it is interesting that the magnitude of strength improvement seems not to be a major factor and this should be investigated in more detail in future. Consequently, the underlying adaptations leading to improved functional capacity (i.e. walking ability and chair rise), as well as main training program variable(s) to achieve these adaptations are yet to be elicited.

One methodological consideration that may influence findings of intervention studies is the choice of strength performance test. As Buckner and colleagues (2016) noted, strength training for maximum lifts (i.e. 1-RM) comprises an element of (task-specific) skill. This may, in some cases, falsely represent functionally relevant increases in strength. As observed in the present study, there was a linear dose-response relationship between training frequency and improved 1-RM performance but this difference was diminished when testing isometrically. It should be noted that, at least in the present study, training was conducted bilaterally using (predominantly) weight-stack devices whereas the isometric knee extension action was tested unilaterally. This non training-specific test in itself would reduce the likelihood of observing training-induced improvements (Abernethy & Jurimäe 1996; Baker et al. 1994). Similar observations have been made when training dynamically and testing isometrically when investigating the effect of training frequency on back extension in older adults (Graves et al. 1990) and even when comparing low- to high-intensity strength training (Mitchell et al. 2012; Van Roie et al. 2013). Nevertheless, overall it could be proposed that the small-to-moderate differences in improved 1-RM between training frequencies observed in various studies may be a consequence of greater practice rather than '*true'* strength gain.

The exact cause of disparity in 1-RM improvement between groups is difficult to discern. All experimental groups demonstrated an increase in muscle activity as assessed by surface EMG amplitude. This measure may or may not represent neural adaptation to strength training (for review see Farina et al. 2014), but it was a systematic change in all groups, whereas increased 1-RM performance was not. Correlation analysis revealed that there was a weak but statistically significant relationship between the change in 1-RM load and the change in EMG amplitude (r=0.23, p=0.041, n=78), which explained only ~5% of the variance. Perhaps improvements in inter-muscle coordination during specific parts of the lift, which would be very challenging to determine experimentally, may have led to improved 1-RM performance and could be considered part of the improved task-specific *'skill'* of 1-RM performance.

To the authors' knowledge, this is the first study to investigate the influence of training frequency on muscle hypertrophy in healthy older individuals. Whereas the present study's 3 months of preparatory training induced gains in muscle mass (approx. 2% increase in lean leg mass, $P<0.05$, unpublished data), neither reduced or maintained or increased training frequency led to further increases in muscle mass during the subsequent 6-month intervention period of the present study (Figure 4). In young subjects, higher training volume using high- to moderate-loads has been shown to be a key element of training for the development of muscle hypertrophy (Campos et al. 2002; Ratamess et al. 2009), but training frequency has been rarely examined directly, and there appears to be no differences between a training frequency of 2 and 3 times per week in novice trainers (Wernbom et al. 2007). Given that the training program in the first 3-month preparation period was not optimized to increase maximum strength or muscle mass it was expected that further increases would have been made during the subsequent 6-month intervention. Certainly there is a large body of evidence showing that initial gains in muscle mass continue over the first year of training (e.g. Häkkinen et al. 2002; Pyka et al. 1994; Taaffe et al. 1996). However, there are also rare observations where older individuals do not gain muscle mass at all, such as the ~70yr old men in Häkkinen et al. (1998).

One possible explanation for the lack of prolonged development in muscle mass in the present study may be that older individuals are thought to be “anabolically resistant” to the effect of strength training, may not demonstrate hypertrophy to the extent of younger individuals (Kraemer et al. 1999) and may require greater protein intake to maximize hypertrophic potential (Moore et al. 2015). Unfortunately for the development of muscle mass, Mero et al. (2013) showed that older individuals habitually consumed less protein (and calories in general) than young individuals, and this was also observed in the present study. The self-reported protein intake of the participants in the present study (range 0.6–1.8 $g \cdot kg^{-1}$ body mass) perhaps indicates a sub-optimal environment for muscle hypertrophy despite the more optimized training program for strength and hypertrophy. Consequently, with no control of diet and/or supplementation during training to optimize protein intake, the present study does not fully allow the effect of training frequency on muscle hypertrophy in healthy older individuals to be determined.

Since there was no improvement in voluntary activation level during unilateral isometric knee extension and no increase in quadriceps muscle mass, it is not surprising that maximum knee extension torque did not increase during the present study. A lack of improved voluntary activation level could be a result of using a non-specific test, as discussed above, or it may indicate that no neural adaptation occurred during the present study. This would seem to be supported by the finding that surface EMG amplitude was no longer significantly changed due to training once normalized to the maximum M-wave amplitude. Alternatively, it may be that the use of single-pulse twitches was not sensitive enough to determine training-induced changes (Herbert & Gandevia 1999). It would be recommended that more detailed measurements assessing muscle activation would be included in future studies.

Interestingly, relationships between increased strength, muscle activity/activation or muscle mass and improved functional capacity were not observed. In fact, the only statistically significant (negative) relationship was observed between change in leg press 1-RM and change in loaded 10-stair climb, and this would be classed as a weak relationship with only 5% of the variance explained. In this regard, it appears that performing strength training (regardless of training frequency) is important to improve functional capacity even in healthy older individuals, but the actual magnitude of strength gain has little or no influence on improved maximum walking speed.

The decision to recommend strength training two-three times per week may have originated from the meta-analysis of Rhea et al. (2003) who were the first to investigate the effect of training frequency on maximum strength development. However, due to the integration of studies utilizing different participant groups, the authors cautioned that *"additional reviews are needed to verify the application of the dose-response trends to those populations"* (p. 458). Subsequently, a meta-analysis in healthy adults over 55 years did not observe the same dose-response relationship for maximum strength (Silva et al. 2014). Regarding muscle hypertrophy, a recent meta-analysis did observe a benefit of higher training frequency but this included studies with age-ranges throughout the lifespan (Schoenfeld et al. 2016). It may well be that the present number of intervention studies examining training frequency does not allow meta-analysis techniques to accurately evaluate its influence on strength, muscle mass, and functional capacity. For example, 17 out of 21 treatments included in study by Silva and colleagues (2014) comprised training of three times per week with majority of studies using 2-3 times per week. This clearly does not allow valid evaluation of a training frequency of one time per week, specifically over the influence of other program variables, such as intensity, volume, number of exercises per muscle group etc., on outcome measures. Therefore, scientists do not currently have sufficient evidence to inform policy makers as to recommendable training frequencies for young or older individuals.

Finally, although habitual physical activity was tracked (daily) throughout the present study, it was done so subjectively using diaries. This method of course is non-blinded, i.e. the participants can see their daily activity level and this may influence the results, and also is open to typical errors of subjective reporting. Future studies may wish to implement objective measures of tracking physical activity in order to verify this finding. Nevertheless, since there were no differences between the groups and that there were no significant relationships between habitual physical activity and any performance outcome measure, it appears that this potential confounding factor did not likely influence the data. In other words, we can be confident that functional capacity did not improve due to physical activity performed externally to the prescribed intervention. Therefore, in general it seems that the act of performing strength training, and not necessarily the increase in strength or muscle mass, is important to improve functional capacity in older individuals, and in order to prescribe individualized training programs for older adults the precise underlying factor should be identified.

5 CONCLUSIONS

The present study found no evidence that higher training frequency would induce greater benefit to maximum walking speed, functional capacity or muscle mass. There is a clear dose-response in dynamic bilateral 1-RM strength but this was not observed during unilateral isometric tests of maximum strength. It appears that in healthy older individuals with some (albeit limited) experience in strength training beneficial functional capacity improvements can be achieved through low frequency training (i.e. 1–2 times per week). This study suggests that a sufficient frequency for whole-body strength training to improve strength, muscle mass and functional capacity are not one-in-the-same and perhaps should be noted in physical activity guidelines for healthy older individuals.

Acknowledgements

The authors would like to thank Mrs. Pirkko Puttonen for her assistance in analysis and all of the dedicated participants and student assistants that took part in this study. We also acknowledge the great work by MSc. Jaakko Forssell during training, testing and analyses. This work was funded by a personal grant to Dr. Simon Walker by the Ministry of Education and Culture, Finland (OKM/56/626/2014).

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