Author(s): Fernández-Lezaun, Elena; Schumann, Moritz; Mäkinen, Tuomas; Kyröläinen, Heikki; Walker, Simon

Title: Effects of resistance training frequency on cardiorespiratory fitness in older men and women during intervention and follow-up

Year: 2017

Version:

Please cite the original version:

Fernández-Lezaun, E., Schumann, M., Mäkinen, T., Kyröläinen, H., & Walker, S. (2017). Effects of resistance training frequency on cardiorespiratory fitness in older men and women during intervention and follow-up. Experimental Gerontology, 95, 44-53. https://doi.org/10.1016/j.exger.2017.05.012

Accepted Manuscript

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PII: S0531-5565(17)30210-3
DOI: doi: 10.1016/j.exger.2017.05.012
Reference: EXG 10055

To appear in: *Experimental Gerontology*

Received date: 6 March 2017
Revised date: 26 April 2017
Accepted date: 15 May 2017

EFFECTS OF RESISTANCE TRAINING FREQUENCY ON CARDIORESPIRATORY FITNESS IN OLDER MEN AND WOMEN DURING INTERVENTION AND FOLLOW-UP

Elena Fernández-Lezaun[1], Moritz Schumann[2], Tuomas Mäkinen[3], Heikki Kyröläinen[1], Simon Walker[1]

[1]Faculty of Sport and Health Sciences and Neuromuscular Research Center, University of Jyväskylä, Finland; [2]Department of Molecular and Cellular Sports Medicine, German Sport University, Cologne, Germany; [3]LIKES-Research Center for Sport and Health Sciences, Jyväskylä, Finland.

Corresponding author:

Simon Walker, PhD

Room VIV223

Faculty of Sport and Health Sciences

University of Jyväskylä

Finland

TEL: +358408054906

simon.walker@jyu.fi

Abstract

This study investigated the effects of resistance training (RT) performed with different frequencies, including a follow-up period, on cardiorespiratory fitness in healthy older individuals. Eighty-eight men and women (69±3 years, 167±9 cm and 78±14 kg) were randomly placed into four groups: training one- (M1=11, W1=12), two- (M2=7, W2=14), or three- (M3=11, W3=13) times-per-week or a non-training control group (MCon=11, WCon=9). During months 1-3, all subjects trained two-times-per-week while during the subsequent 6 months, training frequency was set according to the group. Oxygen consumption (cycling economy: CE), gross efficiency (GE), blood lactate concentrations (La) and heart rate (HR) were evaluated during a submaximal cycle ergometer test. Hemoglobin (Hb), hematocrit (Hct), heart rate (HRrest) and body composition by DXA were also measured at rest. Maximal strength was measured by a 1-RM leg press test. Most improvements in CE, GE, La and HR occurred in all groups during months 1-3. No additional statistically significant improvements were observed during months 4-9, although effect sizes for the change in CE and GE at higher workloads indicated a dose-response pattern in men (CE at 75W: M1 g=0.13, M2 g=-0.58, M3 g=-0.89; 100W: M1 g=0.43, M2 g=-0.59, M3 g=-0.68). i.e. higher training frequency (two- and three-times-per-week versus one-time-per-week) led to greater improvements once the typical plateau in performance had occurred. Hb increased in W1 and W2, while no changes were observed in Hct or HRrest. 1-RM increased from months 1-3 in all intervention groups (except M2) and from month 4-9 only in M3 and in all women intervention groups. During follow-up, maximal strength was maintained but cycling economy returned to the baseline values in all training groups. These data indicate that RT led to significant improvements in cardiorespiratory fitness during the initial 3 months of training. This was partly explained by the RT protocol performed but further improvements may require higher training frequency. These changes are likely to be originated by the improved cardiorespiratory functions rather than neuromuscular adaptations evidenced by a lack of

significant relationship during the intervention as well as the divergent results during follow-up.

Keywords: strength training, cardiovascular, aerobic, elderly, submaximal oxygen consumption.

1. Introduction

The aging process is associated with declines in the neuromuscular and cardiovascular systems and their functions, resulting in decreased muscle mass, maximal strength and maximal aerobic capacity (Frontera et al., 1991; Häkkinen et al., 1998; Izquierdo et al., 2001). While also influenced by genetic and lifestyle factors, these age-related changes may lead to decreases in functional capacity and independence (Chodzko-Zajko et al., 2009). Most activities of daily living such as walking involve submaximal efforts in healthy adult individuals. However, due to the aforementioned losses in maximum capacity the relative intensity increases (Hortobágyi et al., 2003), requiring greater (relative) muscular force and energy expenditure (Frontera and Bigard, 2002). The increasing physiological challenge of performing these daily activities may contribute to the clearly observable age-related decreases in habitual physical activity, which has been associated with higher risks of chronic health conditions (Taylor, 2014).

Resistance training (RT) has not only been shown to increase strength and muscle mass in older individuals (Frontera et al., 1988; Hakkinen et al., 1998), but also to improve maximal aerobic capacity in those subjects whose initial capacity was low (Ozaki et al., 2013). While maximal aerobic capacity has received substantial attention in the literature, only a limited number of studies have investigated the effects of RT on economy of human locomotion, defined as the energy demand for a given absolute submaximal exercise intensity (Saunders et al., 2004). This is surprising, because measuring submaximal oxygen consumption may provide an even better understanding of performing daily living activities than maximal aerobic capacity in older populations.

Findings on submaximal oxygen consumption following RT appear to be contrasting, although only a few studies have investigated movement economy in older people. For example, a group of healthy, untrained 55-75 year-old men and women improved walking economy after 3 months of circuit RT, whereas no changes occurred in a group performing heavy RT (Romero-Arenas et al., 2013). In the study by Hartman et al., (2007), a group of older men and women improved exercise economy in carrying a box while walking but not in unloaded walking after 6.5 months of heavy resistance training. Since training adaptations are specific to the exercise mode, resistance training programs with higher repetitions and shorter rest periods (such as circuit weight training) may be closer to aerobic training in improving economy through cardiovascular adaptations. On the other hand, heavy resistance training may improve movement economy through neuromuscular or tendinous adaptation, such as increased muscle-tendon stiffness (Craib et al., 1996). This may be one possible reason for the contradictory findings and changes in movement economy may also be training/testing-specific.

One important aspect of RT that can influence long-term adaptations is training volume, and a clear dose-response relationship has been identified between RT volume and maximal strength increases (Steib et al., 2010). Since higher training frequency leads to a greater training volume, it would be logical to study this variable. To the best of our knowledge, the effects of resistance training frequency on cardiorespiratory fitness and exercise economy have not yet been investigated. However, this is a potentially important issue to study and determine, particularly given the contradictory findings that have been reported related to maximal strength development; three studies reported similar strength gains (DiFrancisco-Donoghue et al., 2007; Padilha et al., 2015; Taaffe et al., 1999), whereas another study showed greater gains when the training frequency was high (i.e. three- vs. one- and two-times-per-week, and two- vs. one-time per week) (Farinatti et al., 2013).

The aim of the present study was to compare the effects of training frequency (one-, two- or three-times-per-week) during 9 months RT on cardiorespiratory fitness in older men and women. Possible long-lasting influences of the different training frequencies were also assessed during a 6-month follow-up period. It was hypothesized that greater training frequency (i.e. 3 > 2 > 1) would lead to greater training-induced adaptations.

2. Methods

2.1. Subjects

Two thousand older men and women were recruited by letter and randomly selected from all local residents. From those, 450 men and women signed up for the study and were assessed for eligibility. The inclusion criteria for this study were defined as follows: 1) age range 65 to 75 years, 2) less than the 3 hours per week of moderate physical activity, as recommended by the ACSM, 3) no previous resistance training experience, 4) free of cardiovascular diseases, no lower limb disabilities and no use of beta-blockers. Furthermore, prior to the study, the subjects were screened by a cardiologist (including ECG recording, medical history, and joint range of motion examinations) and deemed low-risk to participate. Consequently, out of the original 450 men and women, 98 subjects were accepted to the study. The subjects were informed of the study design and possible risks, and all of them provided written informed consent. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee of the University of Jyväskylä, Finland. Out of the 98 individuals, 5 did not complete the study due to adverse health unrelated to the study, while one dropped out due to a back injury induced by the strength testing, and 4 subjects were not included in the data analysis due to low compliance (<90% attendance). Age and anthropometric data of the remaining 88 subjects are shown in Table 1.

Table 1. Subject characteristics of subjects (n=88) before the training period (mean±SD).

Group	n	Age [years]	Body mass [kg]	Height [cm]	BMI [kg/m^2]
Men 1 (M1)	11	70±2	85±13	174±5	28±3
Men 2 (M2)	7	71±4	91±15	176±3	29±5
Men 3 (M3)	11	70±3	91±14	176±6	29±5
Men control (MCon)	11	70±2	83±7	174±4	27±2
Women 1 (W1)	12	70±3	67±9	160±6	26±3
Women 2 (W2)	14	68±3	74±13	163±4	28±5
Women 3 (W3)	13	69±3	70±9	160±5	28±3
Women control (WCon)	9	69±2	65±9	160±4	26±3

2.2. Study design

At the beginning of the study, subjects were randomly divided into four groups: Men and women training one- (M1, W1, respectively), two- (M2, W2, respectively), or three-times-per-week (M3, W3, respectively) and non-training control (MCon, WCon, respectively). Subjects in the intervention groups performed 9 months of supervised resistance training and a 6-month follow-up period (Fig. 1). Measurements were performed before the intervention period (month 0), following the first 3-month training period (month 3), and following the second 6-month period (month 9). The intervention groups performed additional follow-up measurements 6 months after the end of the intervention (month 15). The control group did not undergo any training intervention but was measured at months 0, 3 and 9. All subjects were instructed to continue with their normal physical activity, which were assessed by means of habitual physical activity diaries.

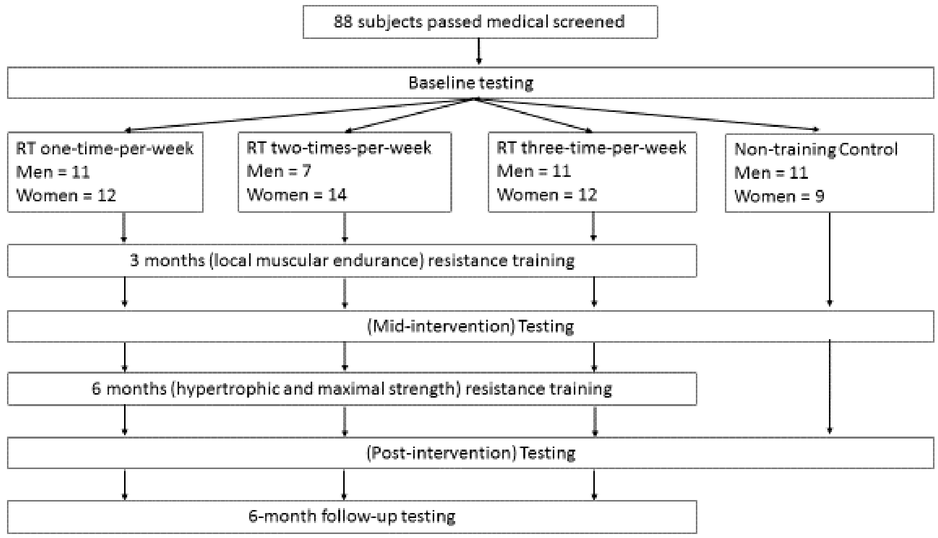

Fig. 1. Study design, randomization and testing time-points

2.3. Resistance training protocol

The resistance training volume was dependent on the intervention group (i.e. one- versus two- versus three-times-per-week). All subjects in the intervention groups trained two-times-per-week on non-consecutive days during the first three months and then continued with different training frequencies for the following six-month period. The main objective of the first three months (Table 2) was to familiarize the subjects with the technique of the resistance training exercises and develop local muscular endurance. The resistance training protocol performed during the subsequent six months targeted improvements in muscle mass, maximal strength and explosive strength in a linearly periodized manner. The resistance training program included exercises for the upper and lower body as well as the core, with a duration of 60 minutes per session. During the second training period (i.e. months 4-9), every fourth week was performed at a reduced intensity (70% of the actual intensity for that training period), allowing the subjects to recover and adapt to the intense training stimulus. All sessions were supervised by qualified instructors and personal resistance-training logs were provided to the subjects, in which the loads and number of exact repetitions in each session were recorded.

Table 2. Resistance training program.

Month	Training goal	Intensity [%1-RM]	Sets	Reps	Rest [min]
1	END	40-60	2	16-20	1
2	END	40-60	2-3	14-16	0.5/2-4*
3	END	40-60	2-3	15	No rest/1*
4	HYP	60-75	2-3	10-12	2
5	HYP	75-85	2-4	8-10**	1-2
6	MAX	85-90	2-4	4-6	2-3
7	HYP	60-85	3-4	8-12	1-2
8	MAX	85-90	3-5	4-6	2-4
9	EXP	30-80	4	6-8	3

END, muscular endurance; HYP, muscle hypertrophy; MAX, maximal strength; EXP, explosive strength. *Supersets: rest between exercises / rest between supersets. **Pyramid sets: set 1 = 10 reps, set 2 = 9 reps, set 3 and 4 = 8 reps.

2.4. Maximal strength

A bilateral dynamic leg press one-repetition maximum (1-RM) test was completed on a horizontal leg press device (David Sports Ltd., Helsinki, Finland) by each subject to assess maximal strength. Prior to testing, all subjects performed a familiarization session where all devices were positioned according to the individual's anthropometry and all measurements were taught and practiced. The strength tests were performed at least three days before the submaximal endurance tests to ensure sufficient recovery between sessions. Warm-up sets consisted of 6, 4, 2 and 1 repetition(s) at 50%, 70%, 90% and 95%, respectively based on the estimated individual 1-RM obtained in the familiarization session. Following the warm-up, 5 maximal single-lifts were allowed to obtain the greatest load the subjects were able to lift, with 1.5 min rest between trials. The subjects were in a seated position at a knee angle of approximately 70º and the attempt was accepted as successful when the knees were fully extended (~180º). Coefficient of variation for 1-RM in this study was 2.0%.

2.5. Cardiorespiratory fitness

The subjects performed a graded submaximal test on a cycle ergometer (Monark Ergomedic 839E, Varberg, Sweden), adapted from the YMCA protocol (Golding et al., 1989). This protocol was chosen because no physician was present during the test. The protocol consisted of 4 times 4-min stages. Women started the test with no external resistance and men at 25W. The workload was increased in both men and women by 25W every fourth minute. Subjects were asked to maintain a pedaling frequency of 60 rpm, which was constantly monitored by the tester. Oxygen consumption was determined breath-by-breath using a gas analyzer (Master Screen CPX, CareFusion, Hoechberg, Germany). Before each test, air-flow calibration was performed manually using a 3L calibration pump. The gas analyzer was calibrated against a certified gas mixture of 16% O_2 and 4% CO_2. Heart rate (HR) was monitored (Polar FT7, Polar Electro Oy, Kempele, Finland) continuously during the test and recorded three times during the last two minutes of each stage. These three values were averaged for further analysis. Capillary blood samples were drawn from the fingertip at the end of every stage for the determination of blood lactate concentrations (La). The samples were analyzed upon immediate completion of the test (Biosen C_line lactate analyzer, EKF Diagnostic, Magdeburg, Germany, coefficient of variation ≤1.5% at 12 $mmol \cdot L^{-1}$) or stored at 4-8 ºC for further analysis on the same day. In order to assure the test remained submaximal, it was the decision of the researcher to stop the test if signs of a maximal effort, such as HR higher than 85% of the theoretical HR_{max} (Gellish et al., 2007), a higher RPE than 18, the inability of the subject to keep the pedaling pace and/or a high RER (greater than 1.10) were observed. Measurements at month 0, 3, 9 and 15 were performed at the same time of day (±1 hour) and with similar air conditions (21-24ºC temperature, 22-30% relative humidity). Values from stage 1 were not included in the analysis due to its low workload. Coefficient of variation for VO_2 was 0.69% for stage 2, 1.73% for stage 3, and 0.91% for stage 4.

Four-minute stages were designed so that steady state was reached during the first 2 min of each stage. Thereafter, breath-by-breath VO_2 values were averaged over the last two minutes of each stage to determine cycling economy. In order to calculate the relative exercise intensities of the submaximal workloads for a better understanding of the perceived effort, VO_{2peak} was estimated through the extrapolation of the estimated HR_{max} from the linear regression analysis of HR and VO_2 values. HR_{max} was estimated using the formula (Gellish et al., 2007): HR_{max} = 206.9 – (age*0.67). Gross efficiency (GE) was calculated from measures of energy expended (EE) and work rate (Moseley and Jeukendrup, 2001):

$$GE (\%) = (Work Rate (W)) / Energy expended (J \cdot s^{-1}) \times 100, where:$$

$$EE (J \cdot s^{-1}) = [(3.869 \times VO_2) + (1.195 \times VCO_2)] \times (4.186/60) \times 1000$$

Typically oxygen consumption has been expressed as milliliters per kilogram (of body mass) per minute. However, previous research has shown that the relationship between oxygen uptake and body mass is not linear (Bergh et al., 1991; Welsman et al., 1996). As such, allometrically scaled values of oxygen consumption may provide a better indication of training-induced changes. Although considerable changes in body mass were not observed in the present study, we analyzed cycling economy both as absolute values ($L \cdot min^{-1}$) and scaled to body mass to the power of 0.75 ($ml \cdot kg^{-75} \cdot min^{-1}$) (Bergh et al., 1991).

2.6. Resting heart rate, hemoglobin and hematocrit

Measurements were conducted between 8:00 and 10:00 in the morning by a qualified lab technician, after a 12-hour fast. After 5 min of quiet sitting, HR at rest was recorded using an automated blood pressure device (Omron M6W, Omron Healthcare Co., Ltd. Hoofddorp, Netherlands) in a seated position with the forearm supported on an adjacent table (elbow angle approx. 90º). Two to three measurements were taken and the lowest value was taken into the analyses. Afterwards, for the biochemical analysis, sterile needles were used to collect venous blood samples from the antecubital vein. Venous blood was drawn into a 3 mL EDTA-tube (Vacuette Tube K2E K2EDTA, Greiner Bio-One GmbH, Kremsmünster, Austria). Immediately after the collection, whole blood samples were analyzed by Sysmex XP 300 (SysmexCo., Kobe, Japan) to obtain hemoglobin concentration (Hb) and hematocrit percentage (Hct). Coefficient of variation was 3.0% for HR at rest, 0.81% for Hb and 1.33% for Hct.

2.7. Body composition

Whole-body tissue composition was measured using Dual-energy X-ray absorptiometry (DXA) (Lunar Prodigy Advance, GE Medical Systems, Madison, United States). Coefficient of variation was 2.2% for total fat mass and 1.1% for lean leg mass, as shown previously in our lab (Walker and Häkkinen, 2014).

2.8. Habitual physical activity diaries

Habitual high-intensity exercise was not permitted throughout the intervention period but subjects were allowed to maintain their typical low-intensity exercise during the present study. Habitual physical activity was self-recorded daily detailing the exercise performed, its duration and subjective intensity. The average (endurance-type) physical activity within each month was then calculated and the total monthly amount of physical activity was averaged for months 0-3 and 4-9. At the follow-up measurements, the subjects only reported the amount of unsupervised resistance training (hours-per-week) performed after the intervention period.

2.9. Statistical analysis

Data are presented as mean±SD. Normal distribution of the data was checked through the Shapiro-Wilk test. When not normally distributed, the data was log transformed. Within- and between-group differences were assessed using repeated measures Analysis of Variance (ANOVA; 3 time points × 4 groups) with three levels (month 0, 3 and 9). Men and women were analyzed separately (i.e. 4 groups for each sex). When appropriate, post-hoc analyses were performed using Bonferroni adjustments. Between-group differences in relative changes were analyzed using a one-way ANOVA. During the follow-up period, the intervention groups' data was assessed for within-group differences and analyzed by paired samples T-Test (month 9 vs. month 15 and month 0 vs. month 15). Between-group effect sizes for these relative changes from month 4 to 9 and month 9 to 15 were calculated using Hedge's *g* with corresponding 95% confidence intervals, where effect sizes are defined as small (<0.3), medium (0.3–0.8), and large (>0.8). Non-parametric tests (independent-samples Mann-Whitney U test and related-samples Wilcoxon signed rank rest) were used for habitual physical activity. In order to assess associations between strength and endurance variables, pearson product-moment correlations were performed. The significance level for all tests was set at *$p<0.05$. Statistical analysis was performed using IBM SPSS Statistics Version 22 (IBM SPSS Inc., Chicago, USA).

3. Results

3.1. Maximal strength

There was a significant main effect for time ($F=36.8$, $p<0.001$ and $F=89.8$, $p<0.001$) and time×group interaction ($F=6.9$, $p<0.001$ and $F=10.7$, $p<0.001$) in men and women, respectively, in dynamic leg press 1-RM (Fig. 2A). Maximal strength statistically increased (except M2: 6±3% at month 3 and 9±9% at month 9, both $p>0.05$) in all intervention groups at month 3 (M1 and W1: 11±5% and 13±8%, $p<0.001$; W2: 11±6%, $p<0.001$; M3 and W3: 8±4% and 13±7%,

$p<0.001$, respectively) and at month 9 (M1 and W1: 11±9% and 17±9%, $p<0.01$ and $p<0.001$; W2: 17±7%, $p<0.001$; M3 and W3: 15±8% and 21±9%, $p<0.001$, respectively) when compared to baseline. Increases from month 4 to 9 were statistically significant in M3 (8±6%, $p<0.01$) and in women in all intervention groups (W1: 4±5%, $p<0.05$; W2: 7±6%, $p<0.01$; W3: 10±7%, $p<0.01$). Effect sizes showed a dose-response relationship in men such that M3 ($g=1.91$, 95%CI=0.88 to 2.94, $p<0.05$) increased more than M2 ($g=1.21$, 95%CI=0.18 to 2.24, $p<0.05$) and particular M1 ($g=0.55$, 95%CI=-0.30 to 1.40, Fig. 3A). A dose-response in women was not as evident with all groups differing from the control (W1: $g=1.34$, 95%CI=0.37 to 2.31, $p<0.05$, W2: $g=1.67$, 95%CI=0.70 to 2.64, $p<0.05$, W3: $g=1.90$, 95%CI=0.88 to 2.92, $p<0.05$, Fig. 3B). Maximal strength in MCon and WCon remained statistically unchanged.

At follow-up, 1-RM decreased when compared to month 9 in M3 and W3 (-6±6% and -7±8%, $p<0.05$, respectively). However, when compared to baseline, all groups that had increased 1-RM during training remained higher at follow-up (range: from 11±5 to 16±8%, $p<0.01$).

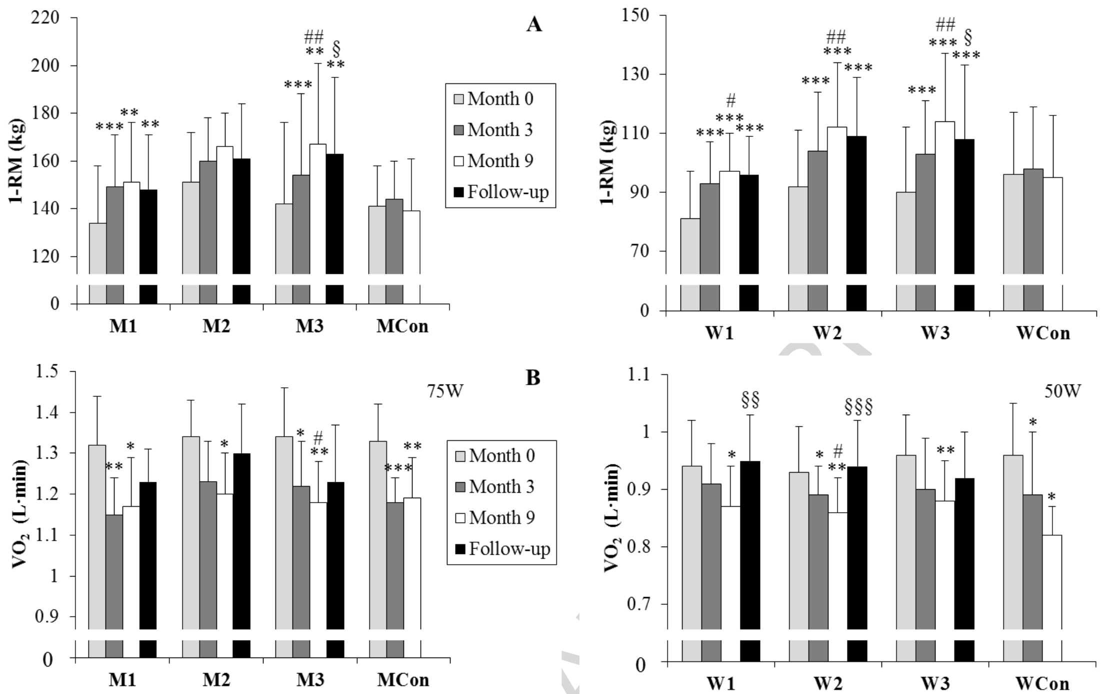

Fig. 2. Mean (±SD) maximal strength (A) and oxygen consumption values (B) at 75W and 50W (i.e. stage 3) of the cycling test in men and women, respectively. *p<0.05, **p<0.01, ***p<0.001 compared to month 0. #p<0.05, ##p<0.01 compared to month 3. §p<0.05, §§p<0.01, §§§p<0.001 compared to month 9.

3.2. Oxygen consumption and gross efficiency

Oxygen consumption values at the different workloads of the submaximal cycling test are presented in Table 3. A significant main effect for time was observed in men in VO_2 at 50W, 75W and 100W ($F=51.0$, $p<0.001$; $F=55.7$, $p<0.001$; $F=41.5$, $p<0.001$, respectively) and in women at 25W, 50W and 75W ($F=40.7$, $p<0.001$; $F=40.7$, $p<0.001$; $F=39.0$, $p<0.001$, respectively). The majority of decreases in submaximal VO_2 in all groups, including control, occurred during the initial 3 months of training (range: from -6 to -19%), representing an improvement in cycling economy. Thereafter, when the groups performed different training frequencies, M3 at 75W (-4±4%, $p<0.05$, Fig. 2B) and W2 at 50W (-3±4%, $p<0.05$, Fig. 2B) and 75W (-4±3%, $p<0.01$) reduced VO_2 compared to month 3. When assessing effect sizes for the change in VO_2 from month 4 to 9, a dose-response pattern was observed in men such that M1 showed no difference, M2 showed a moderate difference (g=-0.58, 95%CI=from -1.55 to 0.38) and M3 a large difference (g=-0.89, 95%CI=from -1.77 to -0.02, $p<0.05$) compared to control at 75W. A similar dose-response pattern was observed at 100W in men (Fig. 3A). This was also the case when comparing W2 and W3 to W1 from month 4 to 9 (Fig. 3B). Similar to the absolute VO_2 values, also oxygen consumption expressed relatively to body mass and scaled to the power of -0.75, followed a similar trend in which most of the improvements were observed during the first 3 months.

At follow-up, VO_2 increased compared to month 9 across all workloads in W1 (9±10% to 9±6%, $p<0.01$) and W2 (7±6% to 8±5%, $p<0.01$), and at 25W and 75W in W3 (6±5% and 5±5%, $p<0.05$, respectively, table 3). Also, effect size analysis showed that W3 moderately tended to maintain more of the training-induced reductions in VO_2 compared to W1 during follow-up at 50W and 75W (g=-0.62, 95%CI=from -1.44 to 0.20 and g=-0.68, 95%CI=from -1.61 to 0.26, respectively). Nevertheless, all groups' submaximal VO_2 values returned to baseline during the follow-up period.

Similar results were observed for GE. A significant main effect for time was observed in men in GE at 50W, 75W and 100W (F=56.6, $p<0.001$; F=67.4, $p<0.001$; F=63.8, $p<0.001$, respectively) and in women at 25W, 50W and 75W (F=41.5, $p<0.001$; F=26.3, $p<0.001$; F=43.5, $p<0.001$, respectively). Again, most groups obtained improved GE after 3 months of training at one or more workloads. Thereafter, when the groups performed different training frequencies, only M3 at 75W (3±3%, $p<0.05$) and W1 (4±4%, $p<0.05$) and W2 (3±4%, $p<0.05$) at 50W, as well as W2 at 75W (4±3%, $p<0.05$) significantly improved when compared to month 3. In men, moderate effect sizes showed a similar dose-response pattern as observed in VO_2 at 75W (M2:

g=0.54, 95%CI=-0.42 to 1.51; M3: *g*=0.71, 95%CI=-0.15 to 1.58) and 100W (M2: *g*=0.51, 95%CI=-0.45 to 1.47; M3: *g*=0.67, 95%CI=-0.19 to 1.53, Fig. 3A).

At follow-up, GE decreased across all workloads in W1 (-9±7% to -10±7%, $p<0.05$), W2 (-8±7% to -9±7%, $p<0.01$) and W3 (-5±7% to -6±5%, $p<0.05$) compared to month 9. Once again, W3 tended to maintain more of the training-induced improvements compared to W1 during follow-up at 50W and 75W with moderate-to-large effect sizes (*g*=0.62, 95%CI=-0.2 to 1.44 and *g*=0.78, 95%CI=-0.16 to 1.72, respectively). Compared to baseline, only M1, M3 and W3 retained an improved GE at follow-up.

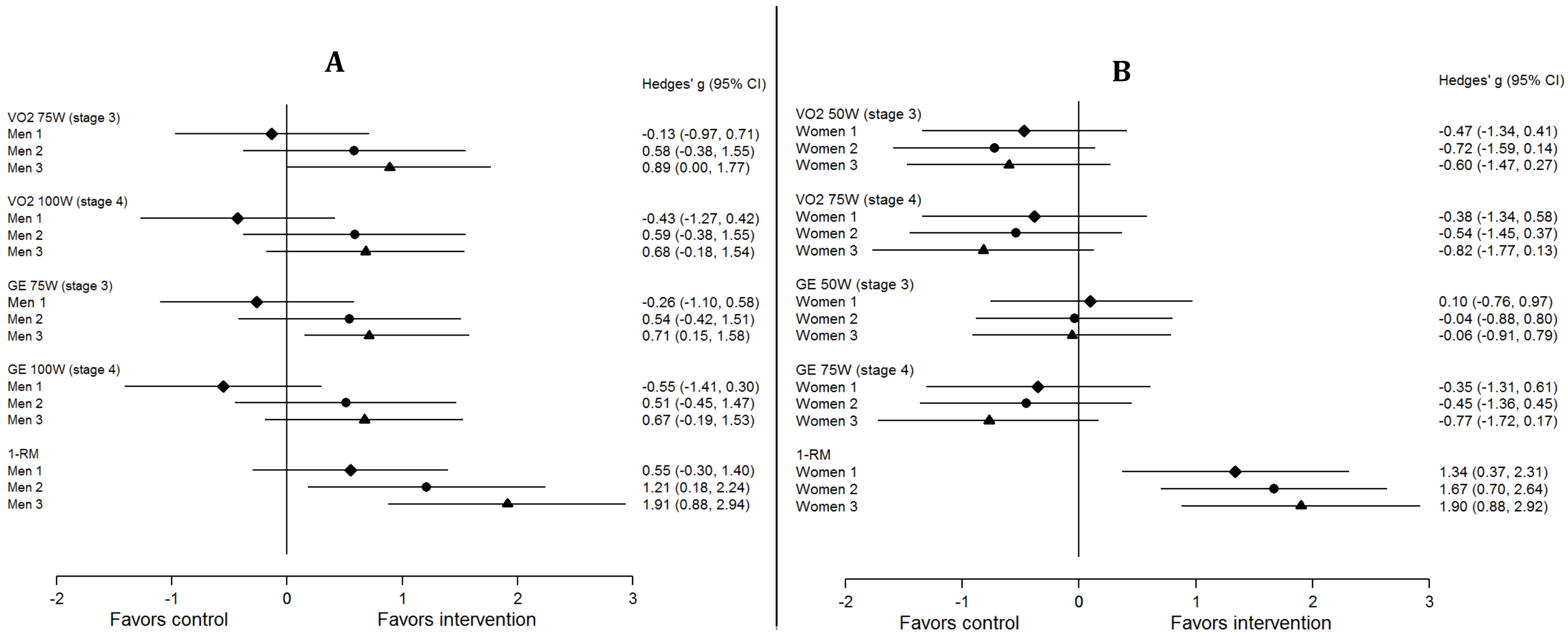

Fig. 3. Hedge's *g* (± 95% confidence intervals) effect sizes for the changes in VO_2, gross efficiency and 1-RM from month 4 to 9 in men (A) and women (B) of the intervention groups versus control. Diamond marker denotes training one-time-per-week, circle marker denotes two-times-per-week, triangle marker denotes three-times-per-week.

Table 3. Mean (±SD) oxygen consumption values during the submaximal cycling test performed at months 0, 3, 9 and 15.

		VO_2 [L·min]			
		25W	**50W**	**75W**	**100W**
M1			*(n=11)*	*(n=11)*	*(n=7)*
	0		1.05±0.09	1.32±0.12	1.62±0.06
	3		0.92±0.08***	1.15±0.09**	1.45±0.08*
	9		0.94±0.1**	1.17±0.12*	1.51±0.07
	15		0.98±0.09	1.23±0.08	1.55±0.09
M2			*(n=7)*	*(n=7)*	*(n=6)*
	0		1.07±0.07	1.34±0.09	1.64±0.11
	3		0.99±0.1	1.23±0.1	1.53±0.09
	9		0.97±0.09**	1.2±0.1*	1.5±0.09
	15		1.02±0.11	1.3±0.12	1.59±0.13
M3			*(n=11)*	*(n=11)*	*(n=11)*
	0		1.04±0.07	1.34±0.12	1.66±0.14
	3		0.98±0.11	1.22±0.11*	1.52±0.12**
	9		0.96±0.09**	1.18±0.1**#	1.48±0.12**
	15		0.98±0.11	1.23±0.14	1.55±0.17
MCon			*(n=11)*	*(n=11)*	*(n=10)*
	0		1.05±0.07	1.33±0.09	1.64±0.1
	3		0.94±0.07***	1.18±0.06***	1.5±0.09***
	9		0.94±0.09**	1.19±0.1**	1.52±0.11*
W1		*(n=12)*	*(n=11)*	*(n=6)*	
	0	0.70±0.08	0.94±0.08	1.19±0.11	
	3	0.65±0.08	0.91±0.07	1.15±0.06	
	9	0.63±0.07*	0.87±0.07*	1.1±0.05	
	15	0.70±0.08§§	0.95±0.08§§	1.23±0.11§§	
W2		*(n=14)*	*(n=13)*	*(n=9)*	
	0	0.71±0.11	0.93±0.08	1.23±0.07	
	3	0.65±0.05*	0.89±0.05*	1.15±0.04*	
	9	0.63±0.07**	0.86±0.06**#	1.10±0.06***##	
	15	0.69±0.07§§§	0.94±0.08§§§	1.20±0.09§§	
W3		*(n=13)*	*(n=13)*	*(n=7)*	
	0	0.73±0.1	0.96±0.07	1.24±0.06	
	3	0.62±0.1*	0.9±0.09	1.15±0.1	

	9	0.61±0.07**	0.88±0.07**	1.11±0.08*
	15	0.65±0.08*§§	0.92±0.08	1.18±0.08§
WCon		*(n=9)*	*(n=9)*	*(n=6)*
	0	0.70±0.11	0.96±0.09	1.27±0.14
	3	0.63±0.11*	0.89±0.11*	1.13±0.15**
	9	0.57±0.04*	0.82±0.05*	1.06±0.06*

*p<0.05, **p<0.01, ***p<0.001 compared to month 0.

#p<0.05, ##p<0.01 compared to month 3.

§p<0.05, §§p<0.01, §§§p<0.001 compared to month 9.

3.3. Heart rate and blood lactate concentrations during cycling

For HR at the different workloads, a significant main effect was observed for time in men at 50W, 75W and 100W (F=9.5, p<0.001; F=24.3, p<0.001; F=33.7, p<0.001, respectively) and in women at 25W, 50W and 75W (F=27.8, p<0.001; F=27.0, p<0.001; F=46.4, p<0.001, respectively). In line with the observed VO_2 reductions, most groups, including control, also reduced HR after 3 months of training at one or more workloads (range: from -6 to -13%, Table 4). Thereafter, when the groups performed different training frequencies no systematic changes occurred, despite W2 further reducing HR at 50W (-4±6%, p<0.05).

For blood La at the different workloads, a significant main effect was observed for time in men at 50W, 75W and 100W (F=8.8, p<0.001; F=37.0, p<0.001; F=58.5, p<0.001, respectively) and in women at 25W, 50W and 75W (F=3.4, p<0.001; F=65.6, p<0.001; F=39.2, p<0.001, respectively). In line with the VO_2 and HR reductions, most groups, including control, also reduced blood La after 3 months of training at one or more workloads (range: from -27 to -61%, Table 4). Thereafter, when the groups performed different training frequencies, only W3 at 25W significantly reduced blood La (-11±32%, p<0.05) and M2 at 100W increased it (14±8%, p<0.05) compared to month 3.

At follow-up, blood La increased at 25W in women in all intervention groups (12±23% to 18±20%, $p<0.05$), at 50W in W1 (12±17%, $p<0.05$) and at 75W in M2 (18±7%, $p<0.05$) compared to month 9. As can be seen from table 4, both HR and La remained lower at month 125 compared to month 0 in all intervention groups at most workloads.

Table 4. Mean (±SD) heart rate and blood lactate concentration values during the submaximal cycling test at months 0, 3, 9 and 15.

		25W		50W		75W		100W	
		HR [bpm]	**La [mmol·L]**	**HR [bpm]**	**La [mmol·L]**	**HR [bpm]**	**La [mmol·L]**	**HR [bpm]**	**La [mmol·L]**
M1									
	0			105±17	1.9±0.5	120±21	2.7±0.8	129±23	3.5±1.4
	3			100±21	1.4±0.6**	107±22*	1.6±0.6**	115±24*	2.0±0.8**
	9			101±15	1.4±0.3*	110±17*	1.6±0.4***	118±21*	2.4±0.7*
	15			101±17	1.7±0.5	108±18**	1.9±0.4*	122±20**	2.7±0.5
M2									
	0			99±16	1.7±0.6	107±14	2.2±1.0	118±11	2.5±0.9
	3			90±13**	1.3±0.7	97±14**	1.5±0.7	108±14*	1.8±0.8
	9			94±13	1.4±0.5	102±12	1.7±0.8	112±13	2.0±0.8#
	15			92±19	1.8±0.9	99±19*	2.0±0.8§	110±19	2.4±1.2
M3									
	0			105±14	2.1±0.5	119±16	2.8±0.5	133±16	4.4±0.8
	3			102±13	1.5±0.7**	110±14**	1.8±0.6***	122±13**	2.9±0.7***
	9			102±13	1.6±0.5*	111±13*	2.0±0.6**	122±14**	3.0±0.8***
	15			96±11**§	1.7±0.8*	105±12***	2.1±0.8**	118±14***	3.1±1.1**
MCon									
	0			108±10	2.2±0.8	119±10	2.9±1.2	129±10	4.0±1.8
	3			101±14	2.2±1.1	109±16*	2.5±1.6	118±12**	3.0±1.8**
	9			101±13	2.0±1.4	108±14	2.3±1.4	119±12*	3.1±1.8*
W1									
	0	107±14	1.8±0.5	122±15	2.5±0.6	135±10	3.8±1.5		
	3	103±12	1.5±0.5*	115±12*	1.9±0.7**	125±6	2.5±1.0*		
	9	105±18	1.3±0.4**	119±21	1.8±0.7**	122±10*	2.3±0.9*		
	15	102±13	1.6±0.5§	113±15*	2.2±0.9*§	122±13**	2.9±1.2**		

W2							
	0	115±17	1.8±0.7	126±17	2.5±1.0	144±15	3.9±1.0
	3	109±16*	1.4±0.7	121±15	1.9±0.7*	134±14*	3.3±1.3
	9	105±16**	1.3±0.4*	117±16**#	1.7±0.6**	131±16**	2.9±1.0*
	15	104±15***	1.5±0.5*§	117±16**	1.8±0.6**	135±15**	3.2±1.0**
W3							
	0	104±11	1.7±0.5	118±15	2.4±0.6	125±12	3.7±1.2
	3	97±15*	1.4±0.6	109±16***	1.7±0.6***	114±10**	2.6±0.8*
	9	94±13**	1.1±0.3***#	106±16***	1.5±0.6***	113±11**	2.2±0.8**
	15	95±16**	1.4±0.5*§§	106±19**	1.6±0.7***	124±20**	2.7±1.2*
WCon							
	0	105±9	1.5±0.6	119±9	2.2±0.7	135±10	3.4±1.1
	3	97±9**	1.2±0.5	111±10*	1.7±0.8*	123±12	2.3±1.3
	9	94±9**	1.0±0.3*	109±10*	1.6±0.6**	123±12	2.5±1.3*

*p<0.05, **p<0.01, ***p<0.001 compared to month 0.

#p<0.05 compared to month 3.

§p<0.05, §§p<0.01 compared to month 9.

3.4. Estimated VO_{2peak} and relative intensities of each workload

For estimated VO_{2peak}, a main effect for time was observed in men (F=13.5, p<0.001) and women (F=10.5, p<0.001) (see supplementary data). Compared to baseline, estimated VO_{2peak} statistically increased in both M1 and W1 at month 3 (16±21% and 10±10%, p<0.05, respectively) and in M3 and W3 at month 9 (12±8% and 11±13%, p<0.01 and p<0.05, respectively). No changes occurred in M2, W2, MCon and WCon. At follow-up, statistical increases were observed in W1 (10±12%, p<0.05) and M3 (6±8%, p<0.05) when compared to month 9.

The relative intensities of each workload of the cycling test throughout the study were as follows: In men, 50W, 75W and 100W corresponded to 44±11, 55±14 and 67±16% VO_{2peak} at month 0; 35±10, 44±13 and 55±17% VO_{2peak} at month 3; 36±11, 45±13 and 57±17% VO_{2peak} at month 9; and 35±10, 45±12 and 56±16% VO_{2peak} at follow-up, respectively. In women, 25W, 50W and

75W corresponded to 43±9, 56±15 and 71±12% VO_{2peak} at month 0; 36±9, 50±12 and 62±14% at month 3; 35±10, 50±14 and 62±15% VO_{2peak} at month 9; and 36±10, 50±13 and 64±15% VO_{2peak} at follow-up, respectively.

3.5. Resting heart rate, hemoglobin and hematocrit

HR at rest decreased in WCon from month 0 to 3 (-5±9%, $p<0.05$). No changes were observed in the other groups. A main effect for time was observed in Hb in women only ($F=15.1$, $p<0.001$). Hb increased in W2 at month 3 (2±2%, $p<0.01$) compared to baseline and in W1 and W2 at month 9 (3±3% and 3±3%, $p<0.01$, respectively). During follow-up, changes in Hb were still significant in W1 when compared to month 0 (3±3%, $p<0.01$, supplementary data). Hct remained statistically unaltered in all groups.

3.6. Body composition

A significant main effect for time was observed in TM in men ($F=4.5$, $p<0.005$) and women ($F=10.6$, $p<0.001$). Compared to baseline, W3 decreased TM at month 9 (-2±2%, $p<0.01$) and at follow-up (-3±3%, $p<0.01$).

A significant main effect for time was observed in men and women in TFM ($F=11.1$, $p<0.001$ and $F=21.4$, $p<0.001$, respectively). Compared to baseline, TFM decreased in men at month 9 in M1 (-10±10%, $p<0.05$) and M3 (-9±13%, $p<0.05$), and in women at month 3 and 9 in W2 (-2±3%, $p<0.05$ and -5±5%, $p<0.01$, respectively) and W3 (-5±5%, $p<0.05$ and -11±8%, $p<0.001$, respectively). Further reductions in TFM from month 4 to 9 were only significant in W3 (-6±6%, $p<0.01$). At follow-up, TFM increased in M1 (7±8%, $p<0.05$) and in W2 (5±5%, $p<0.05$) compared to month 9. Compared to baseline, M3 and W3 maintained a reduced TFM at follow-up (-6±10% and -9±13%, $p<0.05$, respectively).

There was a main effect for time in men and women in TLM (F=3.6, p<0.05 and F=4.3, p<0.05, respectively). Compared to baseline, TLM increased at month 3 in M1 (2±1%, p<0.01) and at month 9 in W3 (3±2%, p<0.05). At follow-up, TLM decreased when compared to month 9 in men in M1 (-2±2%, p<0.05) and in women in all intervention groups (W1: -3±3%, p<0.05; W2: -2±2%, p<0.01; W3: -4±3%, p<0.01, supplementary data).

3.7. Habitual physical activity

At baseline, the amount of self-reported low-intensity endurance-type physical activity did not differ between the groups (M1: 104±97, M2: 81±62, M3: 96±56, MCon: 103±63; W1: 146±57, W2: 117±49, W3: 93±85, WCon: 140±62 min per week, respectively). However, women in the control group performed significantly more low-intensity habitual physical activity during the first three months than the intervention groups (W1: 130±89, W2: 92±77, W3: 128±77 vs. WCon: 263±74 min per week, p<0.05). This was also observed during the following six months except compared to W3 (W1: 116±101, W2: 103±111 vs. WCon: 194±73 min per week, p<0.05). No statistical differences were found in men. During follow-up, men and women from the intervention groups reported an unsupervised RT frequency of 0.6±0.9 (M1) and 0.6±0.7 (W1), 0.0±0.0 (M2) and 1.2±0.8 (W2), and 0.7±0.9 (M3) and 1.3±0.9 (W3) sessions per week.

3.8. Correlation analyses

The initial individual values in 1-RM correlated negatively with the individual changes from month 0 to 3 in 1-RM in men (r=-0.59, p<0.01) and women (r=-0.6, p<0.001) when data from all intervention groups were pooled. The initial individual values in VO_2 correlated negatively with the individual changes from month 0 to 3 in VO_2 in men at 75W and 100W (r=-0.5, p<0.01 and r=-0.49, p<0.05, respectively) and in women at 25W, 50W and 75W (r=-0.51, r=-0.43 and r=-0.66, p< 0.01, respectively).

The individual changes observed in 1-RM from month 0 to 3 were negatively correlated with the individual changes observed in VO_2 in men at 50W and 75W ($r=-0.38$ and $r=-0.4$, $p<0.05$, respectively) and in women at 50W ($r=-0.35$, $p<0.05$) when all data of the intervention groups were pooled. No correlations were found in the control group. Furthermore, no statistically significant correlations were observed from month 4 to 9 between individual changes in 1-RM and VO_2 in the intervention groups.

4. Discussion

To our knowledge, this is the first study comparing the influence of RT frequency on cardiorespiratory fitness in older men and women. The present study design allows determination of the effect of training frequency not only on cardiorespiratory fitness but also on maximal strength and whether improvements in these variables are linked. The main findings were that submaximal oxygen consumption (i.e. cycling economy), gross efficiency, blood lactate concentrations and heart rate improved during the initial 3-month training period in both men and women and further improvements during the next 6 months tended to show a dose-response pattern in men but not women. Particularly, effect size results for cycling economy (Fig. 2) during the two highest workloads support the notion that higher training frequency (two- and three-times-per-week compared to one-time-per-week) led to greater improvements during the latter part of training. However, while blood lactate concentrations and heart rate at follow-up remained improved compared to baseline, cycling economy and gross efficiency returned to the baseline values. These results may also indicate that gains in maximal strength and muscle mass are not major contributors to improved cardiorespiratory fitness since: 1) M2 showed no increase in 1-RM performance but significant improvements in cycling economy, 2) maximal strength was maintained during follow-up while cycling economy decreased, and 3) no relationship was observed between the changes in these variables from month 4-9. The present results partly support our hypothesis (in men) that higher training frequencies would lead to greater adaptations, but there was no clear advantage in training three- versus two-times-per-week for cardiorespiratory fitness.

As would be expected from any training intervention, the majority of improvements in cycling economy, gross efficiency, blood lactate concentrations and heart rate at the different workloads occurred during the first 3 months of RT, when all intervention groups trained two-times-per-week. Heart rate at rest and hematocrit remained unchanged, while hemoglobin increased in women training one- and two-times-per-week (in W1 it was significant only at month 9). Changes in 1-RM during this period were negatively correlated with the changes in VO_2 at 50 and 75W in men and at 50W in women. This finding is supported by the study of Izquierdo et al. (2003), who demonstrated lower submaximal blood lactate levels during the initial 2 months of RT (improved submaximal endurance), but not during the last 2 months in previously untrained older men. Additionally, aerobic-only training was shown to induce similar alterations to cycling economy and blood lactate as the present study, potentially through lower recruitment of higher threshold motor units, whereas strength-only training did not lead to such pronounced changes (Cadore et al. 2011). Collectively, it is reasonable to assume that the early changes in submaximal oxygen consumption reflect the individual subject's initial fitness level and potential for adaptation to training rather than greater changes in strength, particularly since it was observed that low initial strength level was associated with greater training-induced improvements in strength performance. Furthermore, it should be emphasized that the training in the present study during the initial 3 months consisted of medium loads (40-60%1RM) and a rather high number of repetitions (16-20). It was previously shown that such training may increase local muscular endurance but leads to limited gains in maximal strength (Campos et al., 2002), which is supported by the moderate gains in maximal strength during months 1-3 (8 to 13%) of the present study.

In particular, using short rest intervals seems to be an effective aspect to improve exercise economy in older individuals, since Romero-Arenas et al. (2013) observed improved walking economy 3 months after performing circuit training (i.e. short rests) but not in a group that performed traditional heavy-RT when the load lifted was matched between groups. Accordingly, Hartman et al. (2007) observed no improvement in walking economy in a group of older men and women after 26 weeks of heavy-resistance training (2 min inter-set rest). Collectively, these data suggest that cardiorespiratory fitness gains are not mediated by improved maximal strength. However, in some circumstances greater strength may be a contributing factor to improved economy (e.g. greater upper body strength for carrying a box while walking and in climbing stairs in Hartman et al. 2007). Therefore, the RT program design is an important factor when investigating the effect of resistance training on cardiorespiratory fitness in older individuals and also when recommending training strategies for this population.

During the last 6 months of training, when the training frequency differed between the intervention groups, no further statistically significant improvements in the measured physiological variables at the different workloads were found. But when assessing the effect sizes for the change in cycling economy, a dose-response pattern was observed at the higher workloads (75 and 100W for men, and 50 and 75W for women). In men, the obtained effect sizes revealed that the groups training two- and three-times-per-week led to greater gains than control and also the group that trained one-time-per-week. In women, effect sizes also showed that two- and three-times-per-week groups led to greater improvements compared to one-time-per-week group. Higher training frequencies may have induced greater weekly metabolic stress (e.g. larger EPOC responses) that may have stimulated greater cardiorespiratory adaptations when sustained over a long term. No changes were observed in HR at rest, Hb and Hct during this period, which may suggest that central cardiorespiratory and hematological factors did not play a major role in this finding. It should be remembered that the training program involved moderate- to heavyresistances (60-90% 1-RM) and fewer repetitions (4-12), likely to induce blood lactate accumulation (Walker et al., 2015). Previous studies in older individuals have reported improvements in peripheral factors such as increased capillary density and mitochondrial enzyme activity after RT (Frontera et al., 1990; Hepple et al., 1997; Verdijk et al., 2016). These adaptations may, therefore, have also occurred in the present study given that the training program presented a challenge to anaerobic metabolism and a need for oxygen delivery to and waste-product removal from muscle tissue.

During the last 6-month training period in the present study, 1-RM increased in men training three-times-per-week and in women in all intervention groups. Although not statistically significant, strength gains were greater in higher training frequencies (Fig. 2). It could be hypothesized that men in our study needed a higher training frequency (three-times-per-week) in order to further improve strength after initial adaptations. Women, on the other hand, still had a greater potential for improvement due to perhaps a lower level of strength at baseline and thus, all intervention groups increased 1-RM during months 4-9. Most studies examining the effects of training frequency on strength have shown similar gains among groups (DiFrancisco-Donoghue et al., 2007; Padilha et al., 2015; Taaffe et al., 1999) and this is perhaps indicative of the untrained status of subjects in these studies, similarly to the women of the present study. Changes in 1-RM were not correlated with changes in VO_2 from month 4-9, supporting the idea of a limited effect of maximal strength gain on exercise economy. It should be kept in mind, however, that a bilateral leg press exercise may not necessarily be adequately specific to a cycling action to test the influence of maximal strength on cycling economy. Exercise economy has been shown to improve by adding maximal resistance training to the regular endurance training of endurance athletes (Millet et al., 2002; Støren et al., 2008; Vikmoen et al., 2015), possibly due to mechanisms such as altered muscle fiber type recruitment pattern and proportion (Rønnestad and Mujika 2014), but our findings indicate that this may not be a major contributor in older populations. Moreover, in our study, muscle mass only increased in men training one-time-per-week and in women training three-times-per-week as opposed to the commonly observed increases in previous studies (Peterson et al., 2011), suggesting that improvements in cardiorespiratory fitness were not mediated by factors affecting maximal strength, at least in older individuals during moderate aerobic exercise intensities (35-65% estimated VO_{2peak} in the present study).

During follow-up, a lower frequency of unsupervised RT (M1 and W1: ~0.6, M2: ~0.0, W2: ~1.2, M3: ~0.7, W3: ~1.3 times-per-week, respectively) was enough to maintain some of the previous submaximal cycling test improvements, such as heart rate and blood lactate concentrations, but cycling economy (in all groups) and gross efficiency (in M2, W1, and W2) returned to the baseline levels. Thus, when compared to month 0 there were few statistically significant differences in cycling economy or gross efficiency at month 15. Maximal strength was only reduced in men and women who had trained three-times-per-week compared to month 9, but all intervention groups' 1-RM performance remained significantly greater at month 15 than month 0 (except M2 that did not show improvement at any stage of the intervention). Taken together, this dichotomy of maintained maximal strength but reduced cycling economy appears to support our contention that training-induced improvements in these variables were not linked. This is despite the shared importance of training frequency to improve cycling economy and 1-RM performance as highlighted in figure 2.

Estimated VO_{2peak} increased only in men and women training one- and three-times-per-week at a statistically significant level (10-16%, $p<0.05$). Therefore, it does not appear as a result of training frequency, and may be regulated primarily by an individual's adaptability to a training stimulus (Bouchard and Rankinen, 2001), which may have been different between groups. Most studies investigating the effects of RT have shown increases in VO_{2max} in older individuals, particularly when the initial VO_{2max} is low (Ozaki et al., 2013). Similar to the study by Izquierdo et al. (2003), in which further increases in maximal workload after the initial 8 months of RT were not observed, subjects in our study did not significantly increase estimated VO_{2peak} during the last 6 months of training. Therefore, these adaptations appear to be rapidly gained upon initiating RT in previously untrained older individuals.

Finally, it is worth noting that there was a reasonably high proportion of each group that did not complete (i.e. voluntary or tester-enforced withdrawal) all four stages of the submaximal cycling test (completion rates = M1 = 64%, M2 = 86%, M3 = 100%, MCon = 91%, W1 = 50%, W2 = 71%, W3 = 54% and WCon = 67%). After 9 months of training, all groups obtained a 100% completion rate except W1 (75%). This indicates that the subjects were more accustomed to cardiorespiratory stress (either physiologically or psychologically) and may be an important factor in maintaining independence in older populations.

There are several weaknesses of the present study. The fact that the women in the control group improved cardiorespiratory fitness could be explained by the increase in the habitual endurance-type physical activity during the intervention period. This is an unfortunate and unforeseen weakness of the present study, whereby control subjects were instructed to maintain their normal physical activity levels. This finding nevertheless, highlights the importance of tracking physical activity external to the study design in order to draw conclusions as to the efficacy of the intervention protocol. WCon, therefore, could be considered as a low-intensity aerobic exercise group, in which strength performance was not improved. Previous studies have shown lower heart rate at submaximal exercise intensities and at rest after aerobic exercise training (Blumenthal et al., 1989; Ehsani et al., 1991), indicating an enhanced (submaximal) endurance capacity. In comparison with RT, this group demonstrated similar improvements, which partly demonstrates that RT can have a similar effect on aerobic performance as low-intensity aerobic activities in sedentary older individuals (at least initially), but with the additional benefit of greater strength performance. One possibility for the increase in habitual physical activity is that recording in diaries on a daily basis may have been a motivating factor. For future studies, measurement of habitual physical activity should be blinded to the participants, perhaps using accelerometers or other tracking devices. The fact that MCon also improved cardiorespiratory fitness remains unclear, although a lack of familiarization session for the cycle ergometer test (elevating oxygen consumption and heart rate due to anxiety) might be a possibility. However, this perhaps also supports the hypothesis that improvements in cardiorespiratory fitness were mediated by cardiovascular adaptations and not by improved maximal strength.

Secondly, performing a maximal exercise test to exhaustion would have provided more accurate peak oxygen consumption values and identification of aerobic and anaerobic thresholds. However, performing this kind of test requires the presence of a medical doctor and, thereafter, a separate test for cycling economy using the 4-min stage duration of the present study. This was not possible due to financial and time constraints due to the high number of subjects being tested. Consequently, the relative intensities used during the submaximal cycle economy test (35–71% estimated VO_{2peak}) were lower than would be typically used to determine cycling economy, and may partly explain why changes/differences were only observed in the later stages. Nevertheless, performing the submaximal cycling test with longer than typical stage duration (i.e. 4 minute versus 1 minute) to assess cycling economy may be considered a strength of the study.

In conclusion, this study showed that resistance training led to improved cardiorespiratory fitness in older men and women as measured during a submaximal cycling test. After the first 3 months, changes in cycling economy, gross efficiency and maximal strength tended to be larger in the higher-frequency groups. These data highlight the importance of resistance training in increasing not only muscle strength but also cardiorespiratory fitness in older individuals. The data also suggest that more regular resistance training (i.e. higher training frequency) is needed to further improve physical fitness after initial gains and maintain those improvements during times of reduced training.

Acknowledgements

The authors would like to thank BSc and MSc students that contributed research training hours to the project, in particular Alistair Inglis, Mari Turpela, Javier Alonso Serrano and Jaakko Forssell. This work was funded by a personal grant to Dr. Simon Walker by the Finnish Ministry of Culture and Education (OKM/56/626/2014).

References

Bergh, U., Sjödin, B., Forsberg, A., Svedenhag, J., 1991. The relationship between body mass and oxygen uptake during running in humans. Med Sci Sport. Exerc 23, 205–211.

Blumenthal, J.A., Emery, C.F., Madden, D.J., George, Li.K., Coleman, R.E., Riddle, M.W., McKee, D.C., Reasoner, J., Williams, R.S., 1989. Cardiovascular and behavioral effects of aerobic exercise training in healthy older men and women. J. Gerontol. 44, 147–157.

Bouchard, C., Rankinen, T., 2001. Individual differences in response to regular physical activity. Med Sci Sport. Exerc 33, S446-451.

Cadore, E.L., Pinto, R.S., Pinto, S.S., Alberton, C.L., Correa, C.S., Tartaruga, M.P., Silva, E.M., Almeida, A.P.V., Trindade, G.T., Kruel, L.F.M., 2011. Effects of strength, endurance, and concurrent training on aerobic power and dynamic neuromuscular economy in elderly men. J. Strength Cond. Res. 25, 758-766.

Campos, G.E., Luecke, T.J., Wendeln, H.K., Toma, K., Hagerman, F.C., Murray, T.F., Ragg, K.E., Ratamess, N.A., Kraemer, W.J., Staron, R.S., 2002. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. Eur J Appl Physiol 88, 50–60.

Chodzko-Zajko, W.J., Proctor, D.N., Fiatarone Singh, M.A., Minson, C.T., Nigg, C.R., Salem, G.J., Skinner, J.S., 2009. American College of Sports Medicine position stand. Exercise and physical activity for older adults. Med Sci Sport. Exerc 41, 1510–1530.

Correa, C.S., Baroni, B.M., Radaelli, R., Lanferdini, F.J., Cunha Gdos, S., Reischak-Oliveira, Á., Vaz, M.A., Pinto, R.S., 2013. Effects of strength training and detraining on knee extensor strength , muscle volume and muscle quality in elderly women. Age (Omaha). 35, 1899–1904.

Craib, M.W., Mitchell, V.A., Fields, K.B., Cooper, T.R., Hopewell, R., Morgan, D.W., 1996. The association between flexibility and running economy in sub-elite male distance runners. Med Sci Sport. Exerc 28, 737–743.

DiFrancisco-Donoghue, J., Werner, W., Douris, P.C., 2007. Comparison of once-weekly and twice-weekly strength training in older adults. J Sport. Med 41, 19–22.

Ehsani, A.A., Ogawa, T., Miller, T.R., Spina, R.J., Jilka, S.M., 1991. Exercise training improves left ventricular systolic function in older men. Circulation 83, 96–103.

Farinatti, P.T. V, Geraldes, A.A.R., Bottaro, M.F., Lima, M.V.I.C., Albuquerque, R.B., Fleck, S.J., 2013. Effects of different resistance training frequencies on the muscle strength and funcional performance of active women older than 60 years. J. Strength Cond. Res. 27, 2225–2234.

Frontera, W.R., Bigard, X., 2002. The benefits of strength training in the elderly. Sci. Sports 17, 109–116.

Frontera, W.R., Hughes, V.A., Lutz, K.J., Evans, W.J., 1991. A cross-sectional study of muscle strength and mass in 45- to 7 % yr-old men and women. J. Appl. Physiol. 71, 644–650.

Frontera, W.R., Meredith, C.N., O'Reilly, K.P., Evans, W.J., 1990. Strength training and determinants of VO2max in older men. J Appl Physiol 68, 329–333.

Frontera, W.R., Meredith, C.N., O'Reilly, K.P., Knuttgen, H.G., Evans, W.J., 1988. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. J Appl Physiol 64, 1038–1044.

Gellish, R.L., Goslin, B.R., Olson, R.E., Mcdonald, A., Russi, G.D., Moudgil, V.K., 2007. Longitudinal modeling of the relationship between age and maximal heart rate. Med Sci Sport. Exerc 39, 822–829.

Golding, L.A., Myers, C.R., Sinning, W.E., 1989. Y's way to physical fitness: the complete guide to fitness testing and instruction, 3rd ed.

Häkkinen, K., Alen, M., Kallinen, M., Izquierdo, M., Jokelainen, K., Lassila, H., Mälkiä, E., Kraemer, W.J., Newton, R.U., 1998. Muscle CSA, force production, and activation of leg extensors during isometric and dynamic actions in middle-aged and elderly men and women. J. Aging Phys. Act. 6, 232–247.

Hakkinen, K., Newton, R.U., Gordon, S.E., Mccormick, M., Volek, J.S., Nindl, B.C., Gotshalk, L.A., Campbell, W.W., Evans, W.J., Hakkinen, A., Humphries, B.J., Kraemer, W.J., 1998. Changes in muscle morphology , electromyographic activity , and force production characteristics during progressive strength training in young and older men. J. Gerontol. Biol. Sci. 53, 415–423.

Hartman, M.J., Fields, D.A., Byrne, N.M., Hunter, G.R., 2007. Resistance training improves metabolic economy during functional tasks in older adults. J. Strength Cond. Res. 21, 91–95.

Hepple, R.T., Mackinnon, S.L., Thomas, S.G., Goodman, J.M., Plyley, M.J., 1997. Quantitating the capillary supply and the response to resistance training in older men. Pflugers Arch 433, 238–244.

Hortobágyi, T., Mizelle, C., Beam, S., DeVita, P., 2003. Old adults perform activities of daily living near their maximal capabilities. J. Gerontol. Biol. Sci. 58, 453–460.

Izquierdo, M., Häkkinen, K., Antón, A., Garrues, M., Ibañez, J., Ruesta, M., Gorostiaga, E.M., 2001. Maximal strength and power , endurance performance , and serum hormones in middle-aged and elderly men. Med Sci Sport. Exerc 33, 1577–1587.

Izquierdo, M., Häkkinen, K., Ibañez, J., Antón, A., Garrués, M., Ruesta, M., Gorostiaga, E.M., 2003. Effects of strength training on submaximal and maximal endurance performance capacity in middle-aged and older men. J. Strength Cond. Res. 17, 129–139.

Loveless, D.J., Weber, C.L., Haseler, L.J., Schneider, D.A., 2005. Maximal leg-strength training Improves cycling economy in previously untrained men. Med Sci Sport. Exerc 37, 1231–1236. doi:10.1249/01.mss.0000170071.33880.f8

Lovell, D.I., Cuneo, R., Gass, G.C., 2009. Strength training improves submaximum cardiovascular performance in older men. J. Geriatr. Phys. Ther. 32, 117–124.

Millet, G.P., Jaouen, B., Borrani, F., Candau, R., 2002. Effects of concurrent endurance and strength training on running economy and VO2 kinetics. Med Sci Sport. Exerc 34, 1351–1359.

Moseley, L., Jeukendrup, A.E., 2001. The reliability of cycling efficiency. Med Sci Sport. Exerc 33, 621–627.

Ozaki, H., Loenneke, J.P., Thiebaud, R.S., Abe, T., 2013. Resistance training induced increase in VO2max in young and older subjects. Eur. Rev. Aging Phys. Act.

Padilha, C.S., Ribeiro, A.S., Fleck, S.J., Nascimento, M.A., Pina, F.L.C., Okino, A.M., Venturini, D., Barbosa, D.S., Mayhew, J.L., Cyrino, E.S., 2015. Effect of resistance training with different frequencies and detraining on muscular strength and oxidative stress biomarkers in older women. Age (Omaha). 37, 104. doi:10.1007/s11357-015-9841-6

Peterson, M.D., Sen, A., Gordon, P.M., 2011. Influence of resistance exercise on lean body mass in aging adults: a meta-analysis. Med Sci Sport. Exerc 43, 249–258.

Romero-Arenas, S., Blazevich, A.J., Martínez-Pascual, M., Pérez-Gómez, J., Luque, A.J., López-Román, F.J., Alcaraz, P.E., 2013. Effects of high-resistance circuit training in an elderly population ☆. Exp. Gerontol. 48, 334–340. doi:10.1016/j.exger.2013.01.007

Rønnestad, B.R., Mujika, I., 2014. Optimizing strength training for running and cycling endurance performance : A review. Sc 24, 603–612.

Saunders, P.U., Pyne, D.B., Telford, R.D., Hawley, J.A., 2004. Factors affecting running economy in trained distance runners. Sport. Med. 34, 465–485.

Steib, S., Schoene, D., Pfeifer, K., 2010. Dose–response relationship of resistance training in older adults: a meta-analysis. Med Sci Sport. Exerc 42, 902–914.

Støren, Ø., Helgerud, J., Støa, E.M., Hoff, J., 2008. Maximal strength training improves tunning economy in distance runners. Med 40, 1087–1092.

Taaffe, D., Duret, C., Wheeler, S., Marcus, R., 1999. Once-weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. J Am Geriatr Soc 47, 1208–14.

Taylor, D., 2014. Physical activity is medicine for older adults. Postgr. Med J 90, 26–32.

Verdijk, L.B., Snijders, T., Holloway, T.M., Van Kranenburg, J., Van Loon, L.J.C., 2016. Resistance training increases skeletal muscle capillarization in healthy older men. Med Sci Sport. Exerc 48, 2157–2164.

Vikmoen, O., Ellefsen, S., Trøen, Ø., Hollan, I., Hanestadhaugen, M., Raastad, T., Rønnestad, B.R., 2015. Strength training improves cycling performance , fractional utilization of VO 2max and cycling economy in female cyclists. Scand J Med Sci Sport. 26, 384–396.

Walker, S., Häkkinen, K., 2014. Similar increases in strength after short-term resistance training due to different neuromuscular adaptations in young and older men. J. Strength Cond. Res. 28, 3041–3048.

Walker, S., Santolamazza, F., Kraemer, W., Häkkinen, K., 2015. Effects of prolonged hypertrophic resistance training on acute endocrine responses in young and older men. J. Aging Phys. Act. 23, 230–236.

Welsman, J.R., Armstrong, N., Nevill, A.M., Winter, E.M., Kirby, B.J., 1996. Scaling peak VO2 for differences in body size. Med Sci Sport. Exerc 28, 259–265.