EFFECTS OF NINE MONTHS RESISTANCE TRAINING ON CYCLING ECONOMY IN ELDERLY MEN AND WOMEN

Elena Fernández Lezaun

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Department of Biology of Physical Activity
University of Jyväskylä
Supervisors: H. Kyröläinen and S. Walker

ABSTRACT

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The aging process, along with the lifestyle, is associated with loses in functional capacity and independence due to factors such as decreases in muscle mass, strength, and aerobic capacity, among others. Resistance training (RT) has been shown to induce strength and muscle size gains in the elderly. Improvements in maximal endurance capacity have been shown in some studies, while others have found no change. The purpose of the present study was to examine the effects of RT on the cycling economy in the elderly.

A group of 47 older men and women (65-75 years) participated in the study. Subjects were assigned into one of two groups: 1) a training group performing 3 months of RT focusing on local muscular endurance followed by 6 months of RT focusing on maximal strength and hypertrophy, or 2) a non-training control group. Maximal strength (dynamic leg press), submaximal endurance capacity (incremental cycling test), HR at rest, and Hb and Hct were determined before the intervention (PRE), after 3 months (MID) and after 9 months (POST). Cycling economy (CE) was determined as the average oxygen consumption of the last two minutes of each stage and VO_{2peak} was estimated through the extrapolation of the estimated HR_{max} from the linear regression analysis of HR and VO_2 values. All subjects were instructed to record their physical activity levels in diaries.

The main findings were significant improvements in CE in all four groups at MID and POST compared to PRE (except Int W during stage 4). HR response during the cycling test was reduced during stage 2 in the women's groups, during stage 3 in all groups and during stage 4 in both men and women of the intervention groups and men of the control group. Blood La concentrations were only reduced in the training groups. No significant differences between groups were observed for VO_2, HR or La. The results also showed significant increases at MID and POST in 1RM dynamic leg press (MID, Int M, 7%, $p<0.05$, Int W, 13%, $p<0.05$; POST, Int M, 15%, $p<0.01$, Int W, 20%, $p<0.05$) and estimated VO_{2peak} (MID, Int M, 13%, $p<0.05$, Int W, 7%, $p<0.05$; POST, Int M, 11%, $p<0.01$, Int W, 10%, $p<0.05$) in the intervention group only. Relative changes in estimated VO_{2peak} were not significantly different when compared to the control group. No significant changes occurred in HR_{rest}, Hb and Hct in either the intervention or control groups. From PRE to MID the control group tended to perform more endurance exercise when compared to the intervention group ($p=0.068$), which may have led to the observed improvements in CE.

In conclusion, this study showed that a RT protocol focusing on local muscular endurance led to cycling economy improvements as well as increases in estimated VO_{2peak} and 1RM. This type of RT might be an efficient method to enhance both endurance and strength performance in the elderly during short-term training.

Key words: submaximal endurance capacity, strength, cardiovascular adaptations

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LIST OF ABBREVIATIONS

1RM – One repetition maximum

a-vO_2 diff – Arteriovenous oxygen difference

BP – Blood pressure

bpm – Beats per minute

CSA – Cross-sectional area

CE – Cycling economy

EDV – End-diastolic volume

EMG – Electromyography

ET – Endurance training

FS – Fractional shortening

Hb – Hemoglobin

Hct – Hematocrit

HR – Heart rate

HR_{max} – Maximal heart rate

HRR – Heart rate reserve

HR_{rest} – Heart rate at rest

La – Blood lactate

PV – Plasma volume

Q – Cardiac output

RER – Respiratory exchange ratio

RFD – Rate of force development

RPE – Rate of perceived exertion

RT – Resistance training

rpm – Revolutions per minute

SV – Stroke volume

VE – Minute ventilation

VO_2 – Oxygen consumption

VO_{2max} – Maximal oxygen consumption

VO_{2peak} – Peak oxygen consumption

CONTENTS

1 INTRODUCTION

Over the last 50 years, the number of older persons in the world has tripled and it is expected to be more than triple again over the next half a decade. The older population is increasing at a faster rate than the total population. Europe is the area with the highest proportions of older persons (United Nations Department of Economic and Social Affairs Population Division 2002). This aging trend has significant social, political, medical, and economic implications (Bouchard et al. 2012, 272). Lately, the focus has been shifted from increasing the quantity of years to increasing the quality of these since with age, persons become more dependent on the health care system (Becker & Ochshorn 2007).

Aging is associated with several physiologic and cognitive changes including decreased nerve conduction velocity, decreased acuity of senses, onset of arthritis, onset of osteoporosis, decreased strength, decreased maximum heart rate, increased cardiovascular disease, etc. (Taylor & Johnson 2008, xix-xx). However, the aging process is influenced by the person's environmental and social factors, as well as genetic background (Montesano et al. 2012).

Both endurance and resistance training have been shown to benefit the elderly from a physical and psychological health perspective improving their functional capacity and independence. Resistance training specifically has been demonstrated to induce increases in muscle mass and strength in the elderly, as well as improvements in maximal cardiorespiratory capacity in most studies but not in all. However, the question whether resistance training is able to induce changes in economy of movement has received only limited scientific attention.

2 LITERATURE REVIEW

2.1 The aging process

The concept of biological aging refers to the progressive, structural, and functional changes that occur at the cellular, tissue, and organ levels, and that affect all body systems (cardiopulmonary, musculoskeletal, nervous and sensory; Taylor & Johnson 2008, xxv). However, lifestyle and environmental and genetic factors play also an important role in the aging process and researchers find difficulties when trying to differentiate the underlying cause of health conditions. Among the elderly, some of the highest prevalent health conditions related to lifestyle are hypertension, diabetes type 2 and obesity.

In relation to the cardiopulmonary system, changes occur with age in the heart, the pulmonary system and the vasculature. The myocardium is slower to relax after contraction, and cardiac output (the product of heart rate and stroke volume) decreases. There is a reduced compliance of the thorax, which increases the work of the respiratory muscles (increasing respiratory rate and hence, ventilation), residual volume within the lungs increases. There is an increase in the peripheral vascular resistance due to the increased vessel stiffness. As a consequence of these numerous changes, exercise capacity and blood flow to the limbs decrease. Maximum oxygen consumption (VO_{2max}: ml/kg/min), the product of cardiac output (Q) and arterial-venous ($a\text{-}vO_2$) difference, is a common parameter of cardiorespiratory fitness. It has been shown to decrease 10% per decade after age 25 in sedentary persons. Aging is also associated with an elevated risk of cardiovascular diseases, which involve conditions such as hypertension, heart disease, and stroke. This is because of a reduction in the endothelial function and a greater stiffness of the blood vessels (especially of the large arteries), which elevates systolic blood pressure (BP), adding more stress on cardiac function (Taylor & Johnson 2008, 11-18).

Regarding the musculoskeletal system, the most relevant changes are the decrease in muscle cross-sectional area (CSA) due to the gradual disuse of muscle fibers, especially among the fast-twitch fibers due to the lack of explosive movements and the loss of fast motoneurons. Muscle mass, replaced by fat and connective tissue, decreases; the number and size of muscle fibers is reduced and there is a decline in the levels of enzymes in the energy-producing pathways. The decline in the number and size of muscle fibers (sarcopenia), results in impaired mechanical muscle performance, implying decreased maximal muscle strength, power, and rate of force development – RFD (Aagaard et al. 2010). These reductions cause impaired function to perform daily tasks such as climbing stairs, level walking or rising from a chair. Aging also affects in a great degree bone health. Special attention has been paid to osteoporosis, a disease characterized by the weakening of bones and the increase in their risk to fracture. Peak bone mass is achieved between the ages of 20 and 30. Afterwards, it begins to decline. In women the rate of bone loss increases greatly at menopause because of the loss of ovarian hormones. Other factors that affect bone mass and strength are nutrition factors such as insufficient calcium and vitamin D, excessive caffeine, alcohol, and salt intake (McArdle et al. 2010, 60); and lack of weight-bearing physical activities (Bouchard et al. 2012, 222).

Alterations in the nervous system can also be observed in the elderly. Concerning the central nervous system, there is a reduction in tissue, enzymes, receptors, and neurotransmitters. In relation to the peripheral nervous system, nerve conduction decreases as well as the number of excitable motor units in skeletal muscles, both contributing to slower muscle contractions. A functional deficit is then achieved since reflexes are poorer, and the risk of falls rises. Several diseases of the nervous system occur in old ages, such as dementia (i.e. Alzheimer's disease), which causes cognitive problems (Taylor & Johnson 2008, 51-54).

Among the sensory systems changes, the most prevalent are hearing loss; vision impairment (cataracts, glaucoma, diabetic retinopathy, etc.); reduced sensation of pain, temperature, and pressure; and decreased smell and taste sensitivity. These lead to difficulties in communication, loss of basic skills and confidence, poorer balance, and loss of appetite (Taylor & Johnson 2008, 61-67).

Overall, these changes contribute to the main problem associated with aging – the impairment of functional capacity and independence. Since maximal physiological capacities decline greatly with aging, daily activities such as rising from a chair could become a maximal effort in the frail elderly whereas for young healthy non-obese individuals that same task would account for a submaximal effort (Frontera & Bigard 2002).

However, part of these declines in the body systems is due to lifestyle as mentioned previously. Pollock et al. (2015) investigated 55 to 79 year-old highly physically active men and women and concluded that, even though VO_{2max} was associated with age, the relationship between aging and physiological function was highly individualistic and modified by inactivity. Korhonen et al. (2006) studied 18- to 84-year-old male sprinters and observed age-related declines of maximal isometric force, normalized RFD of knee extensors, and size of fast fibers. However, the oldest runners preserved the muscle characteristics, underlining the positive influence of exercise on aging muscle.

2.2 Effects of physical activity on health in the elderly

Physical activity has been shown to have several health benefits in different populations such as children, healthy adults, diabetic patients, elderly, etc. In the elderly, the American College of Sports Medicine (ACSM) recommends a minimum of 30 min of aerobic exercise on 5 days per week for moderate intensity or 3 days per week for vigorous intensity, along with at least 2 days per week of resistance training as well as flexibility and balance, in order to benefit from the positive effects of exercise on health (Nelson et al. 2007).

Epidemiological studies demonstrate a great inverse relationship between physical activity, health and all-cause mortality (Taylor 2014). When exercise intensity and frequency are sufficient to improve muscle strength and aerobic fitness, the risk of functional limitation and disability is reduced in the range of 30-50% (Paterson & Warburton 2010).

Regular aerobic exercise seems to have a positive influence on the cardiovascular system as it increases HR at rest and during exercise, decreases BP, increases VO_{2max}, etc. It leads to health benefits such as decreases in the risk of coronary artery disease, premature death or non-insulin-dependent diabetes mellitus (Taylor & Johnson 2008, 149).

Strength training has been demonstrated to increase muscle mass and strength, preserve bone density and improve dynamic balance; all of which support a reduction in physical impairments and falls in the elderly. It is a countermeasure to combat sarcopenia. It also helps reduce the symptoms of several chronic diseases such as type-2 diabetes and arthritis (Seguin & Nelson 2003).

Emotional health improves as well in the elderly following exercise programs, being able to reduce the signs of depression, improving the quality of sleep, etc. Physical activity has also a positive effect on the cognitive function (Carvalho et al. 2014). Overall, physical activity is associated with a better quality of life in the elderly especially in the domains of functional capacity, autonomy, mental health, vitality, and death (Vagetti et al. 2014).

2.3 Training adaptations in the elderly

The neuromuscular and cardiovascular system's adaptations to training depend on the type of exercise performed. In the next sections the adaptations to endurance (ET), resistance (RT) and concurrent (the combination of ET and RT) training in the elderly will be presented. The term elderly will be referred as 60 to 80 year-old individuals and most of the studies examined will include healthy subjects, absent of cardiovascular diseases, etc.

2.3.1 Endurance training

Endurance training is characterized by long bouts of exercise at submaximal intensities. It induces central and peripheral adaptations that enhance VO_{2max} and the ability of skeletal muscles to generate energy via oxidative metabolism. These are the result of adaptations such as enhanced mitochondrial biogenesis, capillary density, myoglobin content, substrate stores, and oxidative enzymes, as well as increased maximal Q (Cadore & Izquierdo 2013).

The first studies carried out with elderly failed to show any improvements in VO_{2max}. It was then argued that older subjects lost the ability to adapt to endurance exercise training. However, subsequent studies have demonstrated that they do retain the ability to improve their aerobic capacity and suggest that the training stimulus (frequency, intensity or duration) of those previous studies might have been insufficient (Spina 1999).

Green & Crouse (1995) carried out a meta-analysis to delineate the effects of ET on VO_{2max} in older subjects (age ≥ 60 yrs). A total of 29 studies were included, with a publication date ranging from 1965 to 1992. As shown in Table 1, those older subjects who perform 32 min of ET 3 times per week for about 24 weeks improved their VO_{2max} by a mean of 3.5 ml/kg/min. This represents a 14% enhancement. Length of training program, pre-training VO_{2max} and duration of the exercise were the parameters that explained the most variation, respectively. The analysis also demonstrated that both pre-training VO_{2max} and the change in VO_{2max} from pre- to post-training were inversely correlated to age (r=-0.56 for both), suggesting that the ability to alter VO_{2max} declines with age.

Table 1. Means of exercise training parameters and study outcomes (Green & Crouse 1995).

Frequency of exercise (sessions·wk)$^{-1}$	3.26 ± .61	(min: 2.5; max: 5.0; *N* = 31)
Duration of exercise (min·session^{-1})	32.23 ± 11.7	(min: 12.5; max: 60.0; *N* = 31)
Length of training regimen (wk)	24.55 ± 18.0	(min: 6.0; max: 60.0; *N* = 31)
Pretraining $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	24.07 ± 4.8	(min: 12.6; max: 33.7; *N* = 31)
Posttraining $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	27.57 ± 5.6*†	(min: 14.2; max: 37.2; *N* = 31)
Control group $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	24.02 ± 4.37	(min: 17.9; max: 32.6; *N* = 19)
Mean $\Delta\dot{V}O_{2max}$ of exp. group (ml·kg^{-1}·min^{-1})	3.50 ± 1.92‡	(min: 0; max: 7.6; *N* = 31)
Mean $\Delta\dot{V}O_{2max}$ of cntrl. group (ml·kg^{-1}·min^{-1})	.14 ± 1.08	(min: −1.3; max: 2.3; *N* = 19)

* sig. diff. from pretraining value ($P < 0.05$).
† sig. dif. from control group value ($P < 0.05$).
‡ sig. dif. from control group value ($P < 0.05$).
N = number of studies reporting the given value.

Table 2 summarizes the most relevant studies published regarding ET in the elderly.

Table 2. Studies of endurance training on maximal oxygen consumption in healthy older men and women.

STUDY	SUBJECTS			INTERVENTION				RESULTS
	N	Sex	Mean Age	Length (wks)	Frequency	Duration Type ex.	Intensity	↑ VO_{2max}
Blumenthal et al. 1989	33	Both	67	16	3 x/week	60 min Cycling	70% HRR	12% (19 to 21 ml/kg/min) 14% men; 9% women
Ehsani et al. 1991	10	Men	64	48	5 x/week	60 min Walking, running, cycling	60-70% → 70-80% VO_{2max} (brief intervals at 90-100%)	23% (30 to 37 ml/kg/min)
Kohrt et al. 1991	110	Both	64	36-48	3-5 x/week	30 → 50 min Walking, running	60-85% HR_{max}	26% in men (27 to 35 ml/kg/min) 23% in women (22 to 26 ml/kg/min)
Coggan et al. 1992	23	Both	64	36-48	4 x/week	45 min Walking, running	60-70% → 80-85% HR_{max}	29% in men (27 to 35 ml/kg/min) 26% in women (22 to 28 ml/kg/min)
Stratton et al. 1994	13	Men	68	24	4-5 x/week	45 min Walking, running, cycling	50-60% → 80-85% HRR	21% (29 to 35 ml/kg/min)
Fabre et al. 1997	16	Both	64	12	2 x/week	60 min (interval) Walking	2 groups: - HR at V_{th} - 50% HRR	20% only V_{th} group (25 to 30 ml/kg/min)
Pickering et al. 1997	10	Both	62	16	3 x/week	35 min Cycling	Moderate → High	16% (25 to 29 ml/kg/min)
Ahmaidi et al. 1998	11	Both	63	12	2 x/week	30 → 60 min (interval) Walking, running	HR at V_{th}	20% (25 to 30 ml/kg/min)
Beere et al. 1999	10	Men	66	12	3 x/week	30 min Cycling (also arm)	75-90% HR_{max}	18% (18 to 21 ml/kg/min)
Perini et al. 2002	15	Both	74	8	3 x/week	60 min (interval) Cycling	40 → 100% prev. cycle test 77-86% HR_{max}	↑ VO_{2peak}: 18% (19 to 23 ml/kg/min)
Park et al. 2003	8	Women	62	36	3 x/week	60 min Walking, running, cycling	50-60% HRR	11% (22 to 24 ml/kg/min)

The studies selected show a wide range of improvement in VO_{2max} (from 11 to 29%) following ET programs, which demonstrate the variety of training protocols and participants utilized. As an example, Green & Crouse (1995) were unable to include in their meta-analysis the parameter “intensity” due to the variety of methods used to prescribe it (% HR_{max}, % HRR, % VO_{2max}). Some of the investigated studies did compare the older subjects with a non-exercising control group of the same age or with a young-exercising group, while others did not.

Compared to the 14% average enlargement in VO_{2max} reported by these authors, it seems that more recent studies have found greater improvements. Coggan et al. (1992) increased the frequency of training to 4 days/week as well as the duration to 45 min (60-70% → 80-85% HR_{max}) and found an increase of 29% in men and 26% in women. In another study, 13 male subjects achieved a 21% higher VO_{2max} after 45 min of ET 4-5 times per week (Stratton et al. 1994). As Kohrt et al. (1991) noted, most of the endurance exercise programs with the greatest improvement in VO_{2max} (18 to 28%) lasted for ≥26 wk, ≥3 days/wk, 40 min/day, progressing to intensities of 80-90% of HR_{max}.

Other studies have investigated the effects of interval training instead of continuous ET in older men and women, and have found positive results as well (Fabre et al. 1997, Ahmaidi et al. 1998, and Perini et al. 2002). The improvements were around 20% after 60 min of interval training at a HR corresponding to the ventilatory threshold (V_{th}) 2 or 3 times per week, even though the length of the intervention was only from 8 to 12 weeks. Interval training seems to induce a higher stimulus towards the improvement of VO_{2max} in both older men and women.

However, the same authors (Fabre et al. 1997) failed to show any significant change in VO_{2max} in the other group investigated. The intervention also consisted of interval training, but the intensity was set at 50% of HRR (lower than the intensity of the first group). Park et al. (2003) studied 8 older women who performed 3 times per week ET at 50-60% HRR and found a positive change of 11% in their VO_{2max}. Along with these results, Blumenthal et al. (1989) found an improvement of 12% (14% in men and 9% in women) after 4 months of ET at 70% HRR. On the other hand, Stratton et al. (1994) designed a training protocol starting at 50-60% of HRR but increasing to 80-85%

during 6 months and found a 21% enhancement in those older men. Thus, it seems that exercising at intensities around 50 to 70% of HRR does not provide sufficient stimulus to improve VO_{2max} at the same scale as at higher intensities (with either exercise mode – continuous or interval). Another parameter influencing the results is the length of the exercise intervention, since Blumenthal et al. (1991) studied the same subjects during 10 more months of ET and found an overall improvement in VO_{2max} of 18%, compared to the 12% increase during the first 4 months.

During the last two decades, researches have focused on identifying the optimal training mode to improve the cardiorespiratory and neuromuscular systems in the elderly. Therefore, instead of comparing the effects of ET in the elderly versus a control group or a group of young subjects, they have compared it with a group performing resistance training. Cadore et al. (2011) found increased VO_{2max} by 20% after 12 weeks of ET at intensity close to the anaerobic threshold. W_{max} increased by 22% (data not shown in Table 2).

Several studies have aimed to examine the influence of gender, age, and initial fitness on the training-induced changes in VO_{2max}. As mentioned previously, the meta-analysis carried out by Green & Crouse (1995) revealed an age and initial VO_{2max} influence on the relative change in VO_{2max} after training. However, prospective studies have shown different results. Such is the case of the study by Pickering et al. (1997), which showed no correlation between pre-training VO_{2max} and its percentage change. Some demonstrate greater improvements in VO_{2max} in men than in women, although the differences are non-significant in most cases.

Studies such as the one by Ahmaidi et al. (1998), apart from investigating the effects of ET on VO_{2max}, have also assessed the adaptations at submaximal intensities. These authors found that VO_2 at the ventilatory threshold was enhanced by 26% (15 to 19.5 ml/kg/min). At submaximal exercise intensities they found a significant decrease in HR and VE. Fabre et al. (1997) found increased VO_2 at the ventilatory threshold. HR at submaximal intensities has been demonstrated to decrease following ET in the elderly (Ehsani et al. 1991, Blumenthal et al. 1989, Ahmaidi et al. 1998).

Spina (1999) and Coudert & Van Praagh (2000) reviewed the effects of aging (and physical inactivity) on the cardiovascular function. The age-related decrease in VO_{2max} can be explained by a decrease in Q_{max} and a-vO_2 diff. The decline in maximal cardiac output is due to a worsening of myocardial systolic and diastolic function (less left ventricular filling and more afterload), an increase in vascular stiffness, and a decline in the inotropic and chronotropic sensitivity and responsiveness to catecholamines. Therefore, several studies conducted in the elderly regarding ET have aimed to explain the mechanisms behind those improvements in VO_{2max}. These studies have investigated different markers and indexes of central and peripheral adaptations.

Regarding the central adaptations, SV and Q have been shown to be higher at peak exercise following ET in men (Ehsani et al. 1991; Stratton et al. 1994) but not in women (Spina 1993), where they remained unchanged. These increases were mediated by an improved left ventricular systolic performance, as reflected by the enhancement of ejection fraction (EF) and left ventricular end-diastolic volume (LVEDV). EF refers to the percentage of blood pumped out of the ventricle with each contraction and has been studied as an indicator of cardiac function.

In the study by Ehsani et al. (1991), ejection fraction was increased after the training period (66% at rest and 71% at peak exercise before training versus 67% at rest and 78% at peak exercise after training) even though mean BP at peak exercise, used as an index of afterload, was similar before and after training. EF was determined by electrocardiographic-gated equilibrium blood pool imaging. Pickering et al. (1997) also found a greater EF at rest after ET. In the study by Stratton et al. (1994), EF at peak exercise also increased, although in a lower degree (3 versus 7 units). EF at rest remained similar after the intervention period. In the studies by Ehsani et al. (1991) and Stratton et al. (1994), LVEDV index was significantly higher at rest and peak exercise after the training. At peak exercise the increase in EDV correlated strongly ($r=0.95$) with the increase in SV (Ehsani et al. 1991).

An increase in resting EF might reflect the change in the resting sympathetic nervous system, as a result of increased levels of circulating catecholamines and decreased β-adrenergic responsiveness (Coudert & Van Praagh 2000).

Pickering et al. (1997) investigated as well fractional shortening (FS), as it is another way of measuring left ventricle performance. FS is defined as the percentage change in the diameter of the left ventricle between the contracted and relaxed states. The authors found a greater FS at rest measured by echocardiography. A concomitant decrease in end-systolic dimension was also observed, implying a better emptying of the left ventricle with each systole at rest. Plasma volume (PV) was also measured through blood samples. After training, PV, hence blood volume, increased and was correlated with the increase in FS and EF. This reflects the Frank Starling mechanism, in which the heart accommodates the enhanced preload (blood volume) by increasing its contractility and, thus, increasing SV. A lowered [Hb] and Hct were found in the same study in response to training due to hemodilution (expanded PV).

Cardiac hypertrophy as a marker of central adaptation was investigated by Ehsani et al. (1991). Five of the ten men underwent echocardiograms to characterize the pattern of the training-induced left ventricular hypertrophy. The authors found a significant increase in end-diastolic diameter, while the wall thickness to radius ratio was unchanged, suggestive of left ventricular volume overload.

Another marker of central adaptations is HR_{rest}. It has been shown to decrease after ET in some studies (Ehsani et al. 1991; Stratton et al. 1994; Blumenthal et al. 1989), although other authors failed to show any significant changes (Fabre et al. 1997; Perini et al. 2002). In relation to the disparity of results, Coudert & Van Praagh (2000) pointed out in their review that it might be related to the intensity of the exercise programs.

This improvement in cardiac function after ET has been observed in male elderly subjects as mentioned before. However, Spina et al. (1993; cited in Spina 1999) did not find any significant changes in SV, Q or EF at peak exercise or rest in a group of elderly women after completing the same ET protocol as in the study by Ehsani et al. (1991). These results indicate that older women undergo similar changes in VO_{2max} in response to ET as men but with a lack of improvement in left ventricular systolic function or eccentric hypertrophy. Spina (1999) noted in his review that LV filling dynamics to training are influenced by gender: older men show an adaptive response whereas women do not. The same author (Spina 1991) found that in men two-thirds of the VO_{2max} increase was accounted for by an increase in Q_{max}, and one-third was accounted for by a wider a-vO_2 diff. In contrast, the increase in VO_{2max} in women was solely the result of an enhanced a-vO_2 diff (Table 3). It was also reviewed by the same author the reason behind the absence of an increase in Q and SV at maximal exercise in older women. It was then hypothesized that the lack of central adaptations could be the result of the estrogen deficiency that can affect vascular stiffness. A rise in vascular stiffness might lead to an inappropriate rise in aortic impedance, which might raise afterload, and as a consequence, prevent the increase in SV during exercise. Ehsani et al. (1991), on the other hand, failed to show any significant change in a-vO_2 diff at peak exercise.

Table 3. Adaptations to exercise training (Spina 1991).

	$\dot{V}O_{2max}$, *l/min*	*Q̇max, l/min*	*HRmax, beats/min*	*SVmax, ml/beat*	*a-v̄Do₂ ml O₂/dl*
			Men		
Before	2.35 ± 0.1	17 ± 1	170 ± 3	101 ± 5	13.8 ± 0.2
After	2.8 ± 0.1*	19 ± 1*	164 ± 2*	116 ± 5*	14.8 ± 0.3*
			Women		
Before	1.36 ± 0.1	11.2 ± 0.3	161 ± 3	70 ± 2	12.2 ± 0.4
After	1.66 ± 0.1*	11.5 ± 0.4	164 ± 3	70 ± 2	14.4 ± 0.4*

Regarding the peripheral adaptations, in the study by Coggan et al. (1992), muscle biopsies were obtained from the lateral gastrocnemius before and after training. The percentage of type I fibers remained unaltered, whereas the percentage of type IIb decreased and, thus, the percentage of type IIa fibers increased. The cross sectional areas of the type I and the type IIa muscle fibers grew up by 10% and 12%, respectively. Capillary density increased by 21% (257 to 310 capillaries/mm^2), which equals the percent of increase in VO_{2max} in women when expressed in L/min. The increased capillary density resulted from a greater capillary-to-fiber ratio and a greater number of capillaries in contact with each muscle fiber. Regarding the enzyme activity, lactate dehydrogenase activity decreased by 21%, whereas the activity of the mitochondrial enzymes (succinate dehydrogenase, citrate synthase, and β-hydroxyacyl-CoA dehydrogenase) increased by 24-55%. Spina (1999) indicated that these two changes (increased capillarization and activity of mitochondrial enzymatic markers) reflect peripheral adaptations, which would account in women for the enhanced VO_{2max} as a result of a greater a-vO_2 diff after training.

Beere et al. (1999) reported an increased VO_{2max} after training (18%), which was accounted for by changes in systemic a-vO_2 diff (12.5 to 14.3 vol%). They found no change in peripheral oxygen extraction. Both submaximal and peak leg blood flow increased, although no differences were found regarding Q and SV. Thus, the authors suggested that the increased VO_{2max} was due to the redistribution of Q to the exercising limbs.

The vast majority of studies regarding ET have investigated its effects on the cardiovascular system. Perini et al. (2002) included in their study neuromuscular measurements and found no significant changes in the maximal isometric force or muscular endurance.

2.3.2 Resistance training

Resistance training is defined as a structured, planned exercise where the subject exerts an effort against an external resistance (Silva et al. 2014). The primary adaptations to resistance training, include muscle hypertrophy, increased maximal motor unit recruitment, enhanced maximal motor unit firing, elevated spinal motoneuronal excitability, increased voluntary agonist activation, and reduced antagonist co-activation (Häkkinen et al. 1998; Aagaard et al. 2002). These result in enhanced strength and power performance. It has been also shown to promote cardiovascular adaptations, although at a lower magnitude than ET (Cadore & Izquierdo 2013).

In the last three decades, hundreds of articles examining the effect of resistance training in older individuals have been published. Therefore, the following paragraphs aim to summarize the main findings based on a number of reviews and meta-analysis on the topic.

After age 50, as mentioned previously, maximum strength starts to decline at a rate of 12-15% per decade, with more rapid losses above the age of 65 years. Muscle power is also reduced with advancing age. One of the reasons behind it is the decline in muscle mass (number and size of muscle fibers). Frontera et al. (1988) were the first to examine the effects of RT in a group of elderly men. After 12 weeks of RT at 80% of 1RM for knee extensors and flexors, the authors found an increase in strength by 107% and 227%, respectively (Table 4). Strength gains were associated with significant muscle hypertrophy of the midthigh measured by computerized tomography.

Table 4. Effect of resistance training on muscle strength and size of the quadriceps muscle in older individuals (adapted from Macaluso & De Vito 2004).

Authors	Subjects			Training program						% Change	
	Age	Gender	N	Ex mov	Weeks	Sessions / week	Sets	Reps	% 1RM	1RM	CSA
Frontera et al. 1998	60-72	M	12	KE	12	3	3	8	80	107	9
Fiatarone et al. 1990	86-96	M/F	10	KE	8	3	3	8	80	174	11
Charette et al. 1991	64-86	F	13	LP, KE	12	3	6	6	75	28-93	-
Grimby et al. 1992	78-84	M	9	KE	8-12	3	3	8	Isok	-	3
Pyka et al. 1994	61-78	M/F	25	LP, KE	52	3	3	8	75	53-95	-
Lexell et al. 1995	70-77	M/F	23	KE	11	3	3	6	85	163	-
McCartney et al. 1996	60-80	M/F	113	LP	84	2	3	12	80	32	9
Sherrington & Lord 1997	64-94	M/F	21	GWBE	4	7	-	-	-	-	-
Häkkinen et al. 1998b	61	M	10	KE	10	3	3-6	3-15	-	-	9
Häkkinen et al. 1998c	70	M/F	20	KE	26	2	3-6	3-15	50-80	26	6 (F)
Harridge et al. 1999b	85-97	M/F	11	KE	12	3	3	8	80	134	10
Taaffe et al. 1999	65-79	M/F	46	LP, KE	24	1	3	8	80	23-71	-
Tracy et al. 1999	65-75	M/F	23	KE	9	3	3	5-10	-	28	12
Hunter et al. 1999	64-79	M/F	11	KE	12	3	3	8RM	-	39	-
Hortobágyi et al. 2001	66-83	M/F	27	LP	10	3	5	4-12	40-80	35	-
Häkkinen et al. 2001	71	M/F	21	LP	26	2	3-6	10-18	70-80	26	-

CSA = cross-sectional area; Ex mov = exercise movement; F = female; GWBE = general weight bearing exercises; Isok = isokinetic; KE = knee extension; LP = leg press; M = male.

Macaluso & De Vito (2004) reviewed the studies published from 1988 until 2001 and reported that on average, most studies used RT protocols consisting of 8 to 12 weeks, 3 times per week, 3 sets of 8 repetitions at 80% 1RM (Table 4). The relative change in strength after training varied greatly from study to study, possible due to the variations in the protocols and subjects. The authors also summarized that in the first one or two weeks a learning effect occurs, where motor skill coordination and motivation rise. In the following 3 to 4 weeks strength gains occur due to neural adaptations such as increased number of recruited motor units or firing rate and synchronization of the individual motor units; a better coordination of synergistic and antagonist muscles. The following 6 weeks are characterized by an increase in the size (hypertrophy) and strength of the exercising muscles. They noted as well that the greatest improvements are achieved in the first 3 months of RT and in order to maintain the benefits during 6 months, once per week training session is sufficient (Lexell et al. 1995; Trappe et al. 2002).

Muscle power gain after RT was also reviewed by Macaluso & De Vito (2004) due to its association with functional limitations in daily activities in the elderly. RT increased power in most studies, although the gains were generally lower than those for strength (Table 5).

Table 5. Effect of resistance training on muscle power of various muscle groups in older individuals (Macaluso & De Vito 2004).

Authors	Subjects			Training programme						Testing movement	Power gain	Measurement apparatus
	Age	Gender	*N*	Exercise movement	Duration (weeks)	Sessions per week	Sets	Repe-titions	% of 1RM			
Frontera et al. 1988	60–72	M	12	KE	12	3	3	8	80	KE	None	Isokinetic dynamometer
Fiatarone et al. 1994	72–98	M/F	100	KE, HE	10	3	3	8	80	SC	28%	Stair-climbing
Skelton et al. 1995	76–93	M/F	20	Elastic tubing or rice bags	12	3	3	4–8	–	LP	18% (NS)	Nottingham Rig
De Vito et al. 1999	60–70	F	11	Low-intensity general conditioning	12	3	–	–	–	VJ	24%	Force platform
Jozsi et al. 1999	56–66	M/F	17	KE, AP	12	2	3	8–12	80	KE, AP	10–26%	PRM
Izquierdo et al. 2001	64 (2)	M	11	KE, HS, BP	16	2	3–4	8–15	50–80	KE, HS, BP	21–37%	Instrumented weight-stack machines
Earles et al. 2000	77 (5)	M/F	18	LP	12	3	3	10	50–70	LP	22%	PRM
Fielding et al. 2002	73 (1)	F	30	LP	16	3	3	8–10	70	LP	HI: 97% LO: 45%	PRM

AP = arm pull; BP = bench press; F = female; HE = hip extension; HI = high velocity; HS = half-squat; KE = knee extension; LO = low velocity; LP = leg press; M = male; NS = non-significant; PRM = pneumatic resistance training; SC = stair climbing; VJ = vertical jump.

Table 6 shows the most relevant reviews and meta-analysis published regarding resistance training in the elderly. These investigated the dose-response relationship of RT on strength. The parameters included varied among the studies but included intensity of training, type of RT, duration, etc. The studies by Liu & Latham (2009), Steib et al. (2010) and Silva et al. (2014) incorporated only randomized control trials and knee extensors group of muscles, whereas the study by Peterson et al. (2010) included both randomized and non-randomized control trials and upper and lower body strength measures. Despite the inclusion of non-randomized trials, the results did not differ compared with the randomized trials. The reason to include only knee extension exercises was explained by its importance regarding functional capacity in older individuals (gait speed, stair climbing, rising from a chair, etc.).

Table 6. Review articles regarding resistance training in the elderly.

REVIEW	STUDIES INCLUDED		SUBJECTS			INTERVENTION		FINDINGS
	N	**Type**	**N**	**Charact.**	**Mean Age**	**Type**	**Exercise**	**Strength gains**
Liu & Latham 2009	121	RCT	6700	Healthy + unhealthy M & W	> 60 years (most 60 to 69)	PRT	KE	Moderate-large beneficial effect (73 studies, n=3059) High intensity > low/moderate
Peterson et al. 2010	47	RCT + N-RCT	1079	Healthy + unhealthy M & W	67 years	RT	CP, KE (LP too), Lat	LP: +32kg (29%) CP: +10kg (24%) KE: +12kg (33%) Lat: +11kg (25%) Intensity: predictor Age or gender: independent
Steib et al. 2010	22	RCT	1313	Healthy M & W	≥ 65 years	PRT, PT, ecc, isom…	KE (pref. LP)	High-intensity > moderate > low PRT = PT for max strength
Silva et al. 2014	15	RCT	528	Healthy M & W	≥ 60 years	Dyn conc RT	KE	Higher effect sizes: studies with longer durations

RCT = randomized control trials; N-RCT = non-randomized control trials; PRT = progressive resistance training; PT = power training. Ecc = eccentric RT; Isom = isometric RT; Dyn conc RT = dynamic concentric RT; CP = chest press; KE = knee extension; LP = leg press; Lat = lateral pull; M & W = men and women.

The main purpose of the review by Liu & Latham (2009) was to assess the effect of progressive RT on physical function and disability, although a secondary purpose was to investigate the gains in strength. They concluded that most studies used high-intensity protocols, 2-3 times per week for 8-12 weeks. The authors found a moderate-large beneficial effect in strength. High-intensity protocols were more successful than low or moderate ones. The effect was greater in healthy elderly than in those with disabilities (perhaps because of a lower intensity utilized in this second group). The intervention also produced improvements in aerobic capacity measured as VO_{2max}, VO_{2peak} or distance covered in the 6-minute walking test. As expected, they also found superiority of RT for strength gains compared to ET.

Steib et al. (2010) also found a strong evidence for high intensity RT (compared to moderate and low intensity). Most studies included in this meta-analysis had protocols where subjects trained 3 times per week (3 sets of 6-14 reps) for 8-16 weeks. They attempted to compare the dose-response relationship depending on the type of RT, frequency, and intensity. Progressive RT had similar effects on strength than power training, although power training had a greater influence on muscle power and functional capacity gains (moderate evidence). Few studies included in this review compared the frequency of training (limited evidence): two studies found a greater enhancement of strength after twice per week RT compared to once per week, while other showed that 3 times/week was better than 1 or 2 times/week (no significant difference between these two).

The meta-analysis carried out by Silva et al. (2014) included only as well healthy subjects and knee extension exercises. The number of studies (15) gathered was smaller than in the previous review since only dynamic concentric RT was taken into account. Most of the studies reported protocols of 3 sets of 10-15 RM, 2-3 times per week, in accordance with Steib et al. (2010). The results demonstrated higher effect sizes on strength gains in the studies with longer durations. Thus, the authors suggested that it might be a determining variable although care must be taken considering that most studies had similar training programs. The majority of studies were short in duration, raising the importance of neural adaptations. The authors questioned the possibility of other variables such as frequency or intensity if a hypertrophic phase would have occurred (longer intervention durations).

As Macaluso & De Vito (2004) already noted, strength training is an effective way to enhance muscle strength, power output, and muscle mass in elderly populations. Training protocols composed by single or multiple-sets per exercise, intensity from 40 to 85% of 1RM, frequency from 1 to 3 session/week, and duration from 6 to 24 weeks result in average increases in strength of 20-70% (Cadore et al. 2014). Moderate to high intensities (65-80% of 1RM) resulted in greater strength effect-sizes as shown in the meta-analysis by Peterson et al. (2010) and Steib et al. (2010). Muscle power is optimized when training at high movement velocities. Regarding training volume, strength gains are optimized in long duration periods when 3 sets are performed, although in short duration periods (6-12 weeks) similar results have been obtained when compared to only 1 set performed (Cadore et al. 2014).

These authors also support the idea of the importance of power training in the elderly, since declines in muscle power output have been related to functional limitations. The inclusion of explosive concentric contractions as part of the resistance training results in neuromuscular adaptations, such as increases in the maximal power, rate of force development and rapid muscle activation. These contribute to greater enhancements in functional performance.

Recently, another review by Cadore et al. (2014) was published regarding not only strength gains following resistance training, but also other neuromuscular adaptations (Table 7). The effects of RT on muscle hypertrophy have widely been demonstrated. Studies have shown increases between 5 and 15% in CSA and muscle thickness of the quadriceps femoris, in 6 to 30 weeks of duration. The authors also reported the importance of power training since Nogueira et al. (2009) showed that knee extensors muscle thickness increased only after explosive RT (11%), although in the study by Correa et al. (2012) both explosive RT and traditional RT groups showed similar hypertrophy increases (22%). Peterson et al. (2011), in another meta-analysis where 49 studies (n=1328) were included, found also a positive effect of RT on lean body mass. Higher-volume interventions were associated with significantly greater increases in lean body mass, while older subjects experienced less increase.

Table 7 also shows neural adaptations, such as increased EMG magnitude of the agonist muscles, possibly resulting from the increased motor unit activation of those trained muscles and/or increase in their firing frequency. Häkkinen et al. (2001) reported a 12.5% and 22.6% reduction in co-activation in 70-year-old men and women, respectively, as a result of 6 months of heavy RT and explosive exercise. Both muscle tissue and neural adaptations account for the strength gains related to resistance training in the elderly.

Table 7. Neuromuscular adaptations to strength training in healthy elderly (Cadore et al. 2014).

Autor	Period and weekly frequency	Training volume and intensity	Main results
Häkkinen and Häkkinen [63]	12 wk; 2 times/wk	2-5 sets, 3 - 15 repetitions, 30 - 80% of 1RM. Slow and explosive muscle contractions.	↑PT (20%); ↑EMG VL, VM and RF (~20%); ↑CSA QF (9%).
Häkkinen et al. [67]	12 wk; 2 times/wk	2-6 sets, 8-15 repetitions (40-90% of 1RM) unilateral (UNI) and bilateral (BIL). Slow and explosive muscle contractions.	↑1RM (13-19%); ↑EMG (9 - 19%); ↑CSA QF (11-14%).
Häkkinen et al. [60]	24 wk; 2 times/wk	2-5 sets, 3 - 15 repetitions, 30 - 80% of 1RM. Slow and explosive muscle contractions.	↑1RM (21%); ↑PT (36%); ↑RFD (40%); ↑SJ (24%); ↑EMG VL and VM.
Kraemer et al. [62]	10 wk; 3 times/wk	Ondulatory periodization: 2-5 sets of 3-5RM; 8-10RM and 12-15RM.	↑1RM (10%)*; ↑CSA QF (6%).
Häkkinen et al. [64]	24 wk; 2 times/wk	2-5 sets, 3 - 15 repetitions, 30 - 80% of 1RM. Slow and explosive muscle contractions.	↑PT (16%); ↑EMG VL and VM; ↑CSA QF (8,5%); ↑ CSA fiber type I and II.
Häkkinen et al. [47]	10 wk; 2 times/wk	3-6 sets of 6-15 repetitions (50-80% of 1RM). Slow and explosive muscle contractions.	↑1RM (29%); ↑EMG VL and VM; ↑SJ (22%); ↑CSA QF (7%).
Häkkinen et al. [53]	24 wk; 2 times/wk	3-5 sets, 6 - 15 repetitions, 30 - 80% of 1RM. Slow and explosive muscle contractions.	↑PT (36%); ↑EMG VL and VM; ↑RFD (40%); ↑1RM (21%).
Izquierdo et al. [19]	16 wk; 2 times/wk	2-5 sets, 3 - 15 repetitions, 50 - 80% of 1RM. Slow and explosive muscle contractions.	↑1RM (25-41%); ↑PT (26%); ↑ power at 20 - 80% of 1RM (15-60%); ↑CSA QF (11%)
Izquierdo et al. [3]	16 wk; 2 times/wk	3-4 sets, 10 - 15 repetitions, 50 - 80% of 1RM. Slow and explosive muscle contractions.	↑CSA QF (11%); ↑ maximal workload at cycle ergometer; ↑ load at 2 and 4mmol.L^{-1} at cycle ergometer;
Bottaro et al. [11]	10 wk; 2 times/wk	3 sets of 8-10 repetitions (40 - 60% of 1RM); Slow vs. explosive contractions (EC)	↑1RM (25%) in both 2 groups; ↑ power at 60% of 1RM, greater in EC (31 vs. 8%).
Cannon et al. [68]	10 wk; 2 times/wk	3 sets of 10 repetitions (50-75% of 1RM).	↑PT (18%); ↑EMG VL and VM (21%); ↑CSA QF (11%).
Slivka et al. [48]	12 wk; 3 times/wk	3 sets of 10 repetitions (70% of 1RM).	↑1RM (41%); ↑CSA QF (2%).
Nogueira et al. [61]	10 wk; 2 times/wk	3 sets of 8-10 repetitions (40 - 60% of 1RM); Slow vs. explosive contractions (EC)	↑ RF muscle thickness in EC (11%) ↑ BB muscle thickness in both groups (7-14%)
Correa et al. [59]	12 wk; 2 times/wk	First 6 weeks: 2 sets of 12-20RM; Last 6 weeks: 3 sets of 8-12RM; Three ST groups: ST slow-speed (TG); high-speed (PG); and, plyometric training (RG).	↑1RM (20-22%) in the 3 groups; ↑QF MT (22%) in the 3 groups; ↑EMG in the 3 groups; ↑RFD only in the RG group; ↑jump height (25%) only in the RG group;
Pinto et al. [65]	6 wk; 2 times/wk	2 sets. Intensity started at 20RM, progressing to 10RM	↑1RM (23%); ↑QF MT (8-18%); ↑QF MQ (15%).
Radaelli et al. [56]	13 wk; 2 times/wk	1 (low-volume group) or 3 (high-volume group) sets per exercise; started at 20RM, progressing to 10RM.	↑1RM (25-38%); ↑EMG (22-28%); ↑MT (8-14%); ↑MQ (22-25%).

↑, increase; wk, weeks; min, minutes; times/wk, number of training sessions per week; 1RM, 1 maximum repetition; PT, isometric peak torque; SJ, squat jump; CSA, cross-sectional area; QF, quadriceps femoris; VL, vastus lateralis; VM, vastus medialis; RF, rectus femoris; BB, biceps braqui; EMG, eletromyographic signal; RFD, rate of force development; ECC, eccentric; EC, explosive contractions.

It appears clearly that resistance training induces adaptations in the neuromuscular system. However, less clear are its effects on the cardiovascular system. In the review by Ozaki et al. (2013), six out of nine studies in older subjects found a positive influence of RT on VO_{2max}. The increases ranged between 7 and 24%. The authors also found a negative correlation between the initial VO_{2max} and the training-induced change in VO_{2max}, being an initial value lower than 25 ml/kg/min the cutoff. Some of the articles included in this review tried to explain the possible mechanisms behind those improvements in maximal aerobic capacity. Lovell et al. (2009) reported an increase in SV at 40 W (40% VO_{2max}) after RT although no significant changes occurred at 50 or 70% VO_{2max}. HR response was reduced at 40 W and 50% VO_{2max} and a-vO_2 diff was enhanced at 70% VO_{2max} Hepple et al. (1997) found increased capillary-to-fiber perimeter exchange index and Frontera et al. (1990) observed a greater capillary-to-fiber ratio and mitochondria enzyme activity but no change in hemoglobin concentration or plasma volume. Izquierdo et al. (2003) reported a decrease in submaximal blood lactate concentrations at 60, 90 and 120W after 8 weeks of heavy RT but no further changes were observed after the following 8 weeks of training.

2.3.3 Concurrent training

Concurrent training refers to the combination of endurance and resistance training in an exercise program. It has been suggested to be the most effective strategy to enhance both neuromuscular and cardiorespiratory functions as well as functional capacity in the elderly (Cadore & Izquierdo 2013). However, some studies have reported an interference effect since it results in lower strength and power gains when compared to strength training alone (Cadore et al. 2010).

In comparison with RT alone, not so many studies have been published regarding concurrent training in the elderly. Most of them have attempted to compare the neuromuscular and cardiovascular adaptations following concurrent training versus RT or ET alone (Table 8).

Twelve to sixteen weeks of concurrent training in the elderly (Table 8) resulted in VO_{2peak} increases ranging from 8% to 30% and strength gains ranging from 22% to

112% (13% in already active men). Concurrent and ET groups showed similar VO_{2peak} improvements, whereas the RT groups demonstrated no significant change. Regarding strength gains, ET groups developed their strength, although at a lower level than RT and concurrent groups.

Table 8. Cardiovascular and neuromuscular adaptations to concurrent training in the elderly.

STUDY	SUBJECTS			INTERVENTION			RESULTS
	N	Sex	Age	Wks	Frequency	Volume and intensity	
Ferketich et al. 1998	21	Women	60-75	12	E: 3x/wk ES: E + S in each session	E: 30min cycling, 70-80% VO_{2peak} S: 2 sets, 12-15 reps, 80% of 10RM progressing to 12-15RM	↑ VO_{2peak}: E 25%, ES 30% ↑10RM: E 43%, ES 112%*
Wood et al. 2001	36	Both	60-84	12	E: 3x/wk S: 3x/wk ES: E + S in each session	E: 21 to 45min cycling/walking, 60-70% HR_{max} S: 12-15 reps at 75% 5RM until 8-12RM, 1 to 2 sets ES: only 30min E, only 1 set S	↑ 5RM leg ext: E 24%, S 45%, ES 38%
Izquierdo et al. 2004	31	Men	65-74	16	E: 2x/wk S: 2x/wk ES: 1x/wk E + 1x/wk S	E: 30–40 min cycling, at loads (W) of 2, 3, and 4 mmol/L of lactate S: 3–5 sets, 6–15 rep (50–80 % 1RM) slow + fast contractions (20 % of total volume, 30–50 % of 1RM)	↑ 1RM half squat: E 11%, S 41%*, SE 38%* ↑ power: E 5%, S 37%*, SE 38%* ↑ W_{max}: E and SE 11%*, S 4%
Verney et al. 2006	10	Men (active)	70-76	14	3x/wk	Lower body E (12min) + upper body S (12min), 3 bouts each E: 4min cycling, 75-85% HR_{max} + 1min 80-85% HR_{max} S: arms 20 to 10-12RM, chest/shoulder 3 sets 10-12 to 3-6RM	↑ VO_{2peak}: 11% cycling, 18% arm cranking ↑ max isom torque: 13% knee ext, 15% shoulder abd
Cadore et al. 2010	23	Men	61-70	12	E: 3x/wk S: 3x/wk SE: S + E same session	E: 20–30 min cycling, 80–100 % HR at VT_2 S: 18–20RM progressing to 6–8RM	↑ VO_{2peak}: E 20%*, S no change, SE 22%* ↑1RM: E 25%, S 68%*, SE 41%*
Figueroa et al. 2011	24	Women	47-68	12	SE: 3x/wk	SE: 20 min circuit RT (1 set, 12 reps, 9 exs, 60% 1RM) + 20 min treadmill walking (60% HR_{max})	↑ 1RM leg ext: 5kg in SE, no change in control group
Cadore et al. 2012	26	Men	Mean: 65	12	SE and ES, 3x/wk same session	E: 20–30 min cycling, 80–100 % HR at VT_2 S: 18–20RM progressing to 6–8RM	↑ VO_{2peak}: SE 8%, ES 9% ↑ 1RM: SE 35%*, ES 22%

* Significant difference compared to the other group.

The study by Cadore et al. (2010) demonstrated an interference effect since RT resulted in significant greater strength gains than concurrent training. Cadore & Izquierdo (2013) suggested in their review that moderate training frequencies such as that in the previous article (3 times per week) might interfere, whereas similar strength gains were observed in both the RT and concurrent training groups after one session per week of RT and one session per week of ET on separate days (Izquierdo et al. 2014). Intra-session exercise sequence may also influence the magnitude of strength adaptations. Performing RT prior to ET may optimize these (Cadore et al. 2012).

Few studies have investigated muscle hypertrophy following concurrent training in the elderly. Izquierdo et al. (2004) found no difference in the magnitude of hypertrophy (approx. 11%) between the RT and concurrent training groups. In the study by Cadore et al. (2012), although the intra-session exercise sequence influenced strength adaptations, it did not influence muscle mass gains.

Studies investigating the effects of concurrent training on maximal and submaximal neuromuscular activity are scarce as well. Cadore et al. (2010) found a significant increase in the maximal EMG amplitude of the rectus femoris and vastus lateralis only in the RT group (approx. 30%). Greater neuromuscular economy (reduced submaximal EMG to the same absolute load) was also observed only in the RT group. These greater neuromuscular changes occurred in parallel with greater strength gains in the RT group. In the study by Cadore et al. (2012), the authors reported significant changes in the force per unit of active muscle in the older individuals who performed RT prior to ET sequence when compared with the opposite order (27 vs. 15%).

Concurrent training does not impair the cardiovascular adaptations produced by ET alone (Cadore & Izquierdo 2013). Regarding the intra-session sequence in concurrent training, Cadore et al. (2012) found similar increases in VO_{2peak}, W_{max} at cycle ergometer and W at VT_2 (anaerobic threshold) for both groups independently on the sequence order. However, greater enhancements were observed in W at the VT_1 (aerobic threshold) in the group that trained RT prior to ET.

2.4 Economy of movement

Economy of movement is typically defined as the energy demand for a given absolute submaximal exercise intensity, and is determined by measuring the steady-state oxygen consumption (Saunders et al. 2004; Rønnestad & Mujika 2014). Individuals with greater exercise economy have lower oxygen consumption at a predetermined work rate (McArdle et al. 2010, 207).

As mentioned previously, studies carried out in the elderly population have shown an improvement in maximal and submaximal endurance performance after ET, although no significant strength changes occur. On the other hand, RT has been shown to increase muscle strength and aerobic capacity (although at a lower level than ET and not in all studies), emerging as a more beneficial way of exercise for the elderly.

Strength training has been widely shown to have a positive effect on running and cycling economy in trained endurance athletes. Balsalobre-Fernández et al. (2015) performed a meta-analysis of the effect of RT programs on running economy in high-level middle- and long-distance runners and found a large beneficial effect in the five studies reviewed. One of the articles included was by Støren et al. (2008), who found a 5% increase in running economy in a group of distance runners who performed RT for 8 weeks as a supplement to their normal ET. In the study by Vikmoen et al. (2015), a group of female cyclists undertook as well heavy RT for 11 weeks apart from their regular ET, resulting in improved mean power output in a 40-min all-out trial, fractional utilization of O_2 and cycling economy (3.5%). Millet et al. (2002) found as well a 6.9% enhancement in running economy in a group of well-trained triathletes after 14 weeks of heavy RT. Rønnestad & Mujika (2014) concluded in their review that highly trained cyclists benefit from heavy strength training with maximal speed during the concentric phase and runners benefit from the previous training as well as from explosive strength training.

However, investigations carried out in untrained elderly individuals regarding the effects of RT on exercise economy are scarce. Romero-Arenas et al. (2013) compared the effects of 12 weeks of circuit RT and heavy RT on 37 elderly men (55 to 75 years) and found significant improvements in walking economy in both groups. Lovell et al. (2009) in a group of 70 to 80-year-old men did not find any significant VO_2 changes after 16 weeks of RT at a fixed submaximal load of 40W or at a relative intensity of 50% of VO_{2max}, but did find a significant increase at 70% of VO_{2max} in W and subsequently, in VO_2. The increase in VO_2 was not accompanied by an increase in Q despite the increased workload, but by an increase in a-vO_2 diff.

3 RESEARCH QUESTIONS AND HYPOTHESIS

The purpose of the present study was to examine the effect of resistance training over 9 months on cycling economy in a group of healthy older men and women. The study was divided into a first 3-month period of RT focusing on local muscular endurance and a second period of 6 months focusing on strength and hypertrophy.

The research questions and the corresponding hypothesis were as follows:

1. Is cycling economy improved in a group of elderly men and women following a 9-month resistance training program when compared to a control group?

VO_2 at submaximal workloads will be decreased in the training group: improved cycling economy. Improvements in other submaximal endurance parameters such as HR and La will be observed too (Izquierdo et al. 2003; Lovell et al. 2009; Romero-Arenas et al. 2013).

2. Does the magnitude of the adaptations in CE differ between the first three months and the following six months of the intervention?

Relative changes in the first three months will be of a greater magnitude due to the type of RT performed. Higher repetitions and shorter rest periods will be a greater stimulus for the cardiovascular system. Relative changes might be influenced too by the untrained status of the subjects in the first three months.

3. Does the RT program induce chronic adaptations in the estimated VO_{2peak}?

Overall adaptations will be elicited in estimated VO_{2peak} in the intervention group after RT compared to the control group (Peterson et al. 2010; Ozaki et al. 2013).

4. Are changes in CE and estimated VO_{2peak} mediated by strength gains and/ or other neuromuscular and cardiovascular adaptations?

Several physiological adaptations have contributed to the RT-induced improvement in CE and VO_{2max} reported in previous studies, such as increased SV and a-vO_2 diff (greater capillary density). Other possible factors might be increases in muscle mass and blood flow to the exercising muscles, more than strength gains per se (Ozaki et al. 2013).

4 METHODS

4.1 Subjects

A letter was sent in October 2014 to two thousand older men and women who were randomly selected from all residents of the Jyväskylä region. The central records bureau (Väestorekisterikeskus) provided the information about the individuals. From those, 450 responded and signed up for the study. In January 2015, after applying the inclusion criteria, 110 subjects completed a medical examination. A group of forty-nine older men and women (age range 66-75 years) was finally recruited to participate in the present study, which was part of a larger research. The inclusion criteria to be eligible for the study included: 1) age range 65 to 75 years, 2) less than the 3 hours per week of moderate physical activity recommended by the ACSM, 3) no previous resistance training experience, 4) free of cardiovascular diseases, no lower limb disabilities (cartilage damage, replaced joints, etc.) and no beta blockers usage. The medical examination consisted of measurements of resting ECG and self-reported medical questionnaire. A qualified physician had to clear the subjects to participate in the study. The subjects were informed of the study design and possible risks, after which all provided written consent. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee of the University of Jyväskylä, Finland.

The subjects' anthropometric data are shown in Table 9. Height was measured with a wall-mounted tape measurer (accuracy 0.1 cm) and body mass with a digital scale with an accuracy of 0.1 kg (Seca 708, Seca, Espoo, Finland). BMI was calculated as the body mass (kg) divided by the square of the subjects' height (m). No differences were found between sexes in any of the anthropometric data.

Table 9. Anthropometric data of the participants obtained before the start of the intervention.

Group	n	Age [years]	Body mass [kg]	Height [cm]	BMI [kg·m^{-2}]
Int M	12	70±3	90±14	176±6	29±5
Cont M	11	70±2	83±7	174±4	27±2
Int W	15	69±3	72±10	161±5	28±3
Cont W	9	69±2	65±9	160±4	26±3

Values shown as mean±SD. Int M = intervention men; Int W = intervention women; Cont M = control men; Cont W = control women.

4.2 Study design

The study began in February 2015 and lasted over 9 months until December 2015 (Figure 1). Prior to the intervention period, subjects were tested for their maximal strength and submaximal endurance performance. After the pre-measurements, subjects were randomly assigned either to the training or the control group. Two participants from the control group dropped out the study. One was unable to perform the basal measurements and another one dropped out after the mid-training measurements due to health reasons unrelated to the study. This led to a total of 47 subjects completing the entire study (men n=23, women n=24) divided in intervention men and women (Int M and Int W) and control men and women (Cont M and Cont W).

The training group performed 9 months of resistance training. During the first 3 months, the training protocol consisted of 2 sessions per week of resistance training with the objective of developing muscular endurance. During the last 6 months, the subjects performed 3 sessions per week of resistance training focusing first on muscle hypertrophy, then on maximal strength and finally, on explosive strength training. The control group did not undergo any training intervention. All subjects were instructed to continue with their normal physical activity and nutrition habits and they registered them in diaries. All subjects were given nutrition counseling.

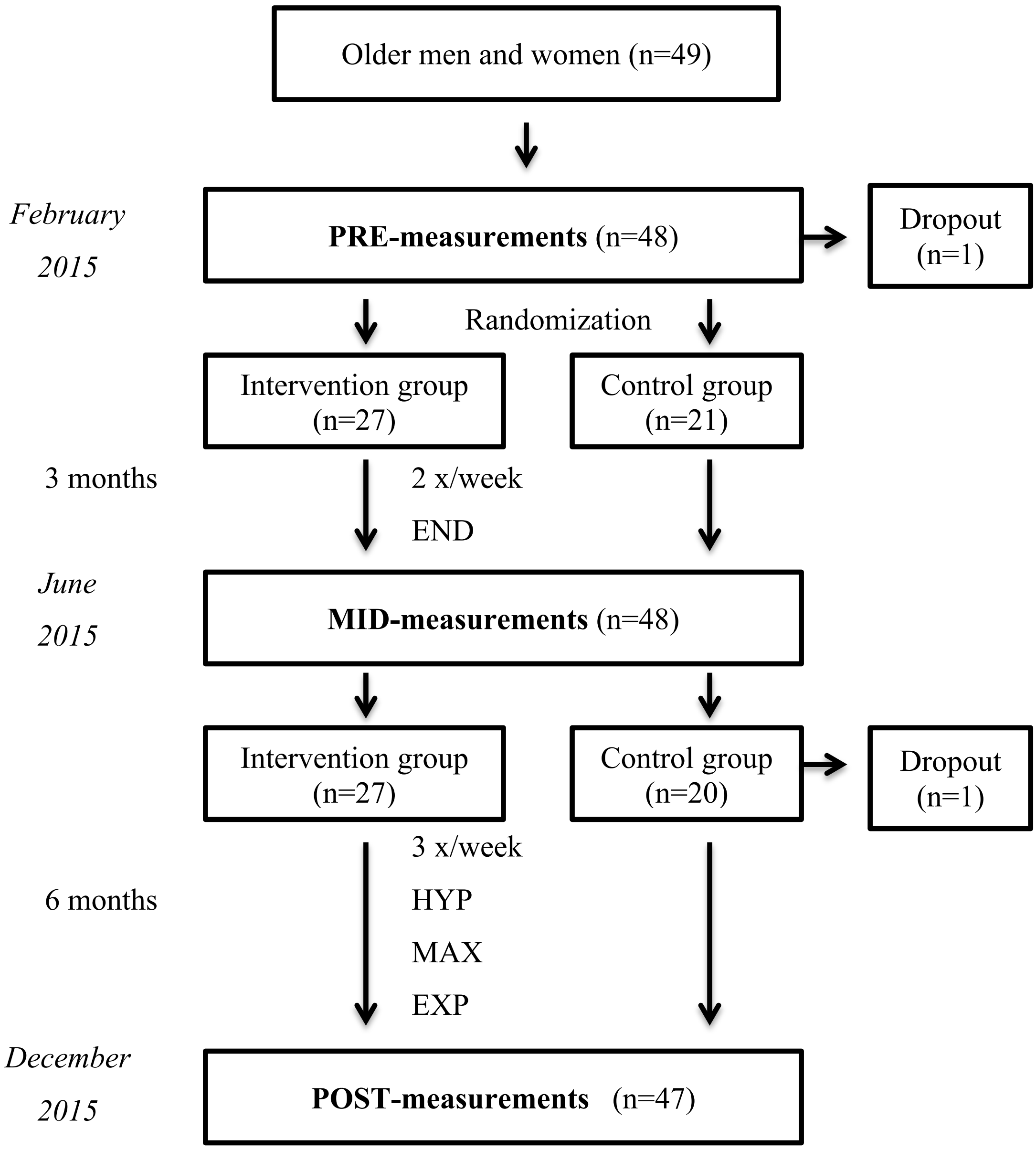

Figure 1. Overview of the study design. END = muscular endurance; HYP = hypertrophy; MAX = maximal; EXP = explosive. Two participants dropped out due to being unable to perform the PRE-measurements and the second, due to illness unrelated to the study.

4.3 Training protocol

The training included a total of 9 months of resistance training. The purpose of the first 3 months was to acquaint the subjects with the resistance training program, the equipment and the exercise techniques. It focused on developing local muscular endurance capacity to prepare them for the following period of high-intensity RT and to improve their endurance capacity. The training protocol of the following 6 months was designed to improve muscle hypertrophy, maximal strength and explosive strength in a linearly periodized manner. Table 10 illustrates the RT protocol in detail.

Table 10. Strength training program.

Month	Training type	Intensity [%1RM]	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.

Each training session started with a 5 min warm-up on a cycle ergometer, rowing device or treadmill. The training protocol included exercises for the upper and lower body, and for the core, which varied depending on the training period (Table 11). It was designed to last approximately one hour per session. The subjects were advised to cool-down after training for another 5 min, stretching or performing low intensity aerobic exercise. The participants were instructed to leave at least 48 hours of rest between training sessions. In the last six months, the fourth week of every section was performed at a reduced intensity (70% of the actual intensity for that training period), allowing the subjects to recover from the previous weeks and preparing them for the following period. During all training sessions qualified instructors supervised the subjects. They provided advice concerning the progression of the training loads and the proper exercise techniques, and answered questions and motivated the subjects. A superiority of supervised versus unsupervised training in the elderly has been shown before

(Boshuizen et al. 2005; Lacroix et al. 2015). Personal training logs were provided to the subjects, where they recorded the loads and number of exact repetitions in each session.

Table 11. Performed strength training exercises during the study.

		Month								
	Exercises	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Lower body	**Leg press (m)**	X	X	X	X	X	X	X	X	X
	Knee extension (m)	X	X	X	X	X	X	X	X	X
	Knee flexion (m)	X	X	X	X	X	X	X	X	
	Seated calf raise (m)	X	X	X	X	X	X	X		
	Split squat (b/d)							X		X
	Straight leg calf raise (m)							X	X	X
	Squat (m/d)							X	X	X
	Deadlift (d/b)							X		X
Upper body	**Chest press (m)**	X	X	X	X	X	X			
	Lateral pulldown (m)	X	X	X	X	X	X		X	
	Triceps extension (p)	X	X	X	X	X				
	Shoulder press (m)	X	X	X	X	X	X			
	Seated row (m)	X	X	X	X	X	X		X	X
	Biceps curl (p)	X	X	X						
	Shoulder raises (d)		X	X					X	
	Deck peck (m)					X	X	X	X	
	Biceps curl (b/d)				X	X				
	Bench press (b)							X	X	X
	Single arm row (d)							X		
	Shoulder press (d)							X	X	X
	Assisted pull-ups (m)							X		X
Core	**Sit-ups (bw)**	X	X	X	X	X	X	X	X	X
	Back extension (m)	X	X	X	X	X	X	X		X
	Abdomen curl (m)	X	X	X	X		X		X	
	Back extension (bw)				X	X	X	X	X	X

M=machine; p=pulley; d=dumbbell; b=barbell; bw=body weight. Lower body refers to the lower extremities; upper body to the arms, back and chest; and core to the lower back, the pelvis and the abdominal wall.

4.4 Data collection

Prior to the beginning of the training intervention, baseline measurements (strength, submaximal aerobic capacity, resting heart rate, and hemoglobin and hematocrit) were performed. All subjects performed a familiarization session for the strength measurements prior to testing. The strength tests were performed two days before the submaximal endurance capacity tests to ensure enough recovery time between sessions. The same measurements were performed after the 3-month RT focusing on local muscular endurance and at the end of the 9 months intervention. All subjects recorded their daily exercise through physical activity diaries throughout the duration of the study.

4.4.1 Maximum dynamic strength

A one repetition maximum (1RM) test in dynamic leg press was completed by each subject to assess strength. Participants were scheduled for testing at the same time of day (±2 hours) and with similar ambient conditions at PRE-, MID- and POST-training measurements. A warm-up consisting of 6, 4, 2 and 1 reps at estimated 50%, 70%, 90% and 95%, respectively, from the 1RM values collected in the familiarization preceded strength testing. Rest periods between sets were 1 min in length. After the warm-up protocol, the 1RM test started. Rests between trials were of 1.5 min. The objective was to complete the test within 5 attempts, until obtaining the greatest load the subjects were able to lift. This was recorded as the 1RM value, to the accuracy of 1.25 kg. The test was performed on a horizontal dynamometer (David Sports Ltd., Helsinki, Finland), where subjects were placed in the seated position at a knee angle of approximately 70° (68.4±3.5º). Subjects were instructed to extend their knees to 180° (without locking them), while holding the handles on the device and maintaining their buttocks and back in contact with the seat and backrest, respectively. All subjects were encouraged verbally throughout the test. Coefficient of variation was 2.04%.

4.4.2 Submaximal endurance capacity

The subjects performed a graded submaximal cycling test on a cycle ergometer (Monark Ergomedic 839E, Varberg, Sweden). The test consisted of 4 stages of 4 min (16 min in total). The initial workload for women and men was 0W and 25W respectively, and it was increased by 25W every fourth minute. The subjects were instructed to maintain a pedaling frequency of 60±2 rpm. The seat height was individually adjusted at the beginning of baseline measurements and kept constant for the mid- and post-training measurements. Subjects were instructed to keep calm during the test and breathe normally. They were encouraged verbally throughout to maintain the pace. Oxygen consumption was determined continuously 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 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 taken from the fingertip during the last 30 seconds of every stage to measure blood lactate concentrations. The samples were analyzed upon immediate completion of the test using Biosen C_line lactate analyzer (coefficient of variation ≤1.5% at 12 mmol·L; EKF Diagnostic, Magdeburg, Germany) or stored at 4-8 ºC for further analysis on the same day. Subjects were asked for their RPE twice during the last two minutes of each stage (Borg's 20-point scale). It was the decision of the researcher to stop the test if there were signs of a maximal effort, such as a HR higher than the 85% of the theoretical HR_{max}, a higher RPE than 18, the inability of the subject to keep the pedaling pace and/or a high RER (greater than 1.10). After the termination of the test, subjects cycled for a further two minutes at a low intensity as a cool down. Pre-, mid- and post-training measurements were performed at the same time of day (±1 hour) and with similar ambient condition (21-24ºC temperature, 22-30% relative humidity). Coefficient of variation was 0.69% for stage 2, 1.73% for stage 3, and 0.91% for stage 4.

Cycling economy: Oxygen consumption (VO_2) values were averaged over the last two minutes of stages 2, 3 and 4. Data from stage 1 was not used for the cycling economy analysis since the loads did not imply sufficient efforts.

VO_{2peak}: Peak oxygen consumption (VO_{2peak}) was estimated through the extrapolation of HR_{max} from the linear regression analysis of the HR and VO_2 values. HR_{max} was estimated using the formula by Gellish et al. (2007): $HR_{max} = 206.9 – (age*0.67)$.

4.4.3 Resting heart rate, hemoglobin and hematocrit

The measurements were conducted by a qualified lab technician between 8:00 and 8:30 in the morning, on a different day to the strength and submaximal endurance capacity test sessions. Heart rate measurements were taken using an automated blood pressure device (Omron M6W, Omron Healthcare Co., Ltd. Hoofddorp, Netherlands). Two recordings were obtained for each subject, using the right arm. The lowest HR value was used for the analysis. 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 the hemoglobin concentration and hematocrit percentage. Coefficient of variation was 0.81% for Hb and 1.33% for Hct.

4.4.4 Physical activity diaries

Before the start of the study, all subjects were asked to report their weekly average physical activity time. Those who performed more than 180 min per week were not included in the study. All subjects participating in the investigation were asked to continue with their usual levels of physical activity throughout the whole intervention period. They were required to record when applicable, day-by-day the type of exercise performed, and its duration. Subjects completed the diaries starting from March and until November. The average endurance-type physical activity per week was then calculated for each month and the data was grouped and averaged for the period before and after the mid-measurements.

4.5 Statistical analysis

Conventional statistical methods were used to obtain means, standard deviations (SD), and area-under-the-curve (AUC). Normal distribution of the data was checked through the Shapiro-Wilk test. When not normally distributed, the data was log transformed. Between-group differences at each measurement point were analyzed using a one-way analysis of variance (One-way ANOVA) with Tukey as post-hoc test. Within-group differences were assessed by repeated measures analysis of covariance (ANCOVA) with Bonferroni adjustments as post-hoc test. Associated values at PRE were used as the covariate to eliminate the possible effect of initial variances on training outcomes. In the event of a significant interaction, a repeated measures analysis of variance (ANOVA) was performed on each group individually. Nonparametric tests were used for resting heart rate (Independent-samples Kruskal-Wallis and related-samples Wilcoxon signed-rank tests) and endurance exercise (Independent-samples Mann Whitney U test). Pearson product-moment correlation for strength and endurance variables was performed. The significance level for all tests was set at $^*p<0.05$. Statistical analysis was performed with IBM SPSS Statistics Version 22 (IBM SPSS Inc., Chicago, USA).

5 RESULTS

5.1 Baseline measurements

Regarding the data obtained from the cycle ergometer tests, HR during each stage was not statistically different within sexes or between the intervention and control groups. There was a main effect (F=3.19, p=0.033) between groups in the area-under-the-curve (AUC) for blood La but post-hoc tests did not show any significant differences between groups. VO_2 during stage 2 was significantly higher for Cont M compared to Int W and Cont W, as well as for Int M compared to Int W. During stage 3 and 4, VO_2 was only significantly higher for Cont M when compared to Int W (Table 12).

Table 12. Oxygen consumption (VO_2), heart rate (HR) and area-under-the-curve (AUC) for blood lactate (La) concentration values for the submaximal cycle ergometer test at the PRE-measurements.

Group	VO_2 [ml·kg^{-1}·min^{-1}]			HR [bpm]			La AUC
	Stage 2	Stage 3	Stage 4	Stage 2	Stage 3	Stage 4	[mmol·L]
Int M (n=12)	11.6±1.6	15.0±2.2	18.6±2.6	107±15	121±16	134±15	5.7±1.4
Cont M (n=11)	12.7±1.0	16.1±1.4	19.7±1.6	108±10	119±10	129±10	5.8±2.4
Int W (n=15)	10.2±1.1$^{\#}$	13.4±1.2**	16.7±1.7*	103±11	116±15	121±12	4.3±1.4
Cont W (n=9)	10.7±1.4**	14.6±1.8	19.3±1.9	105±9	119±9	135±10	4.1±1.1

Values are shown as mean±SD. Stage 4: Int M (n=12), Cont M (n=10), Int W (n=9), Cont W (n=6). #p<0.05 refers to significant differences compared to Int M and Cont M. *p<0.05 and **p<0.01 refer to significant differences compared to Cont M.

No significant differences were found at baseline between the intervention and control groups within sexes for the one repetition maximum (1RM) in dynamic leg press, hemoglobin (Hb) and hematocrit (Hct) concentrations, although statistical differences were observed between men and women. Estimated VO_{2peak} and resting HR were not statistically different between men and women or between intervention and control groups (Table 13).

Table 13. One repetition maximum (1RM) in dynamic leg press, estimated peak oxygen consumption (VO_{2peak}), resting heart rate (HR_{rest}), hemoglobin (Hb) and hematocrit (Hct) obtained during the PRE-measurements.

Group	1RM [kg]	VO_{2peak} [ml·kg^{-1}·min^{-1}]	HR_{rest} [bpm]	Hb [g·L]	Hct [%]
Int M (n=12)	139±33	26.2±4.2	67±13	148±14	44±5
Cont M (n=11)	142±17	30.4±6.2	69±10	150±8	44±2
Int W (n=15)	91±21$^{###}$	27.5±6.4	71±12	136±10$^{#}$	41±3$^{#}$
Cont W (n=9)	96±21$^{###}$	25.6±4.8	66±5	130±5$^{#}$	39±2$^{#}$

Values are shown as mean±SD. HR_{rest}: Int M (n=11), Cont M (n=11), Int W (13), Cont W (n=8). #$p<0.05$ and ###$p<0.001$ refer to significant differences compared to Int M and Cont M.

5.2 Submaximal endurance performance before and after training

5.2.1 Cycling economy

All four groups improved cycling economy (CE) during stages 2 and 3 of the submaximal cycle ergometer test from PRE to POST. During stage 4, all groups reduced VO_2 although in Int W it was not statistically significant.

During stage 2, a significant time x group interaction was observed (F=3.388, p<0.01, adjusted for initial level) between genders but not between control and intervention groups within the same gender. VO_2 was reduced from PRE to POST in all groups (Int M: 11.6±1.6 vs. 10.8±1.0 ml·kg^{-1}·min^{-1}, p<0.05; Int W: 10.2±1.1 vs. 8.8±1.3, p<0.01; Cont M: 12.7±1.0 vs. 11.4±0.9, p<0.01; Cont W: 10.7±1.4 vs. 8.9±0.9, p<0.01). MID to POST changes were not statistically significant in any group (Figure 2).

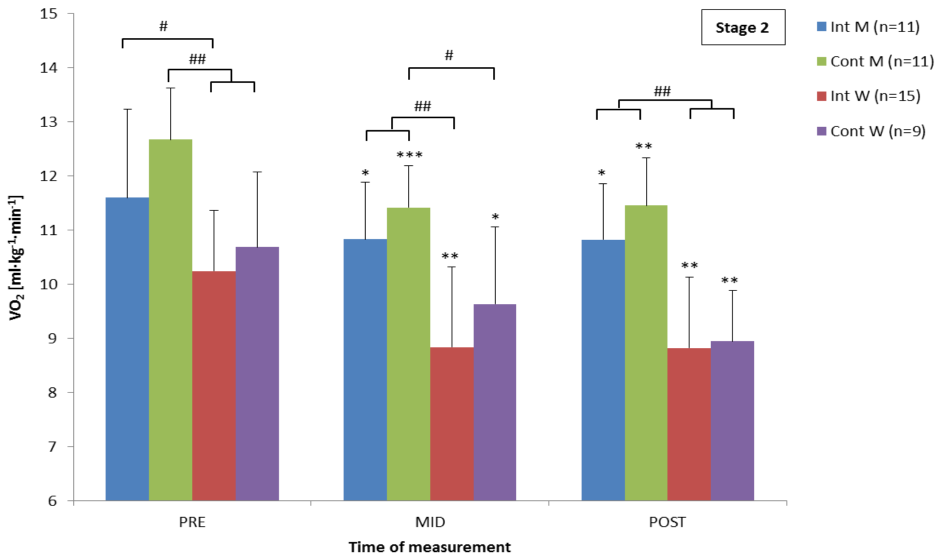

Figure 2. Oxygen consumption (VO_2) absolute values during stage 2 of the endurance capacity test. *p<0.05, **p<0.01 and ***p<0.001 refer to within-group significant differences compared to PRE. #p<0.05 and ##p<0.01 refer to significant differences between sexes.

During stage 3, there was no time x group interaction (F=1.019, p=0.68). A main effect for time was observed (F=4.497, p<0.01) when adjusted for the VO_2 values at PRE. Figure 3 depicts VO_2 reductions from PRE to POST (Int M: 15.0±2.2 vs. 13.4±1.5 ml·kg^{-1}·min^{-1}, p<0.01; Int W: 13.4±1.2 vs. 12.6±1.7, p<0.01; Cont M: 16.1±1.4 vs. 14.4±0.9, p<0.01; Cont W: 14.6±1.8 vs. 12.9±1.4, p<0.05). Changes from MID to POST were not statistically significant in any group.

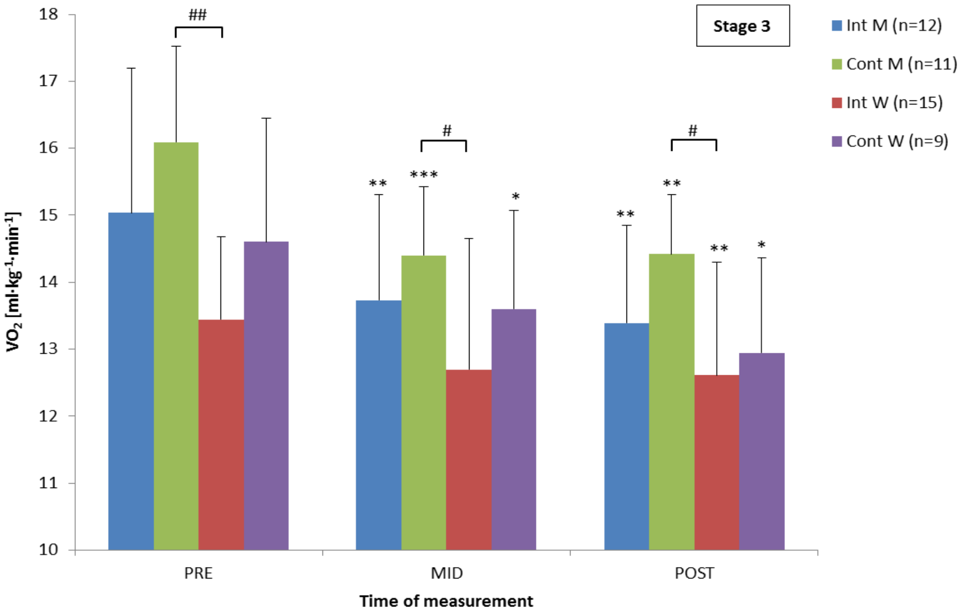

Figure 3. Oxygen consumption (VO_2) absolute values during stage 3 of the endurance capacity test. *p<0.05, **p<0.01 and ***p<0.001 refer to within-group significant differences compared to PRE. #p<0.05 and ##p<0.01 refer to significant differences between sexes.

During stage 4 (Figure 4), there was no time x group interaction (F=1.63, p=0.153). A significant main effect for time was found (F=4.181, p<0.05) when adjusted for the initial level. VO_2 was reduced from PRE to POST in Int M (18.6±2.6 vs. 16.8±1.9 $ml \cdot kg^{-1} \cdot min^{-1}$, p<0.001), Cont M (19.7±1.6 vs. 18.4±1.3, p<0.01), and Cont W (19.3±1.9 vs. 16.8±1.8, p<0.01). PRE to POST changes in Int W were not statistically significant. MID to POST changes in VO_2 were not statistically significant in any group.

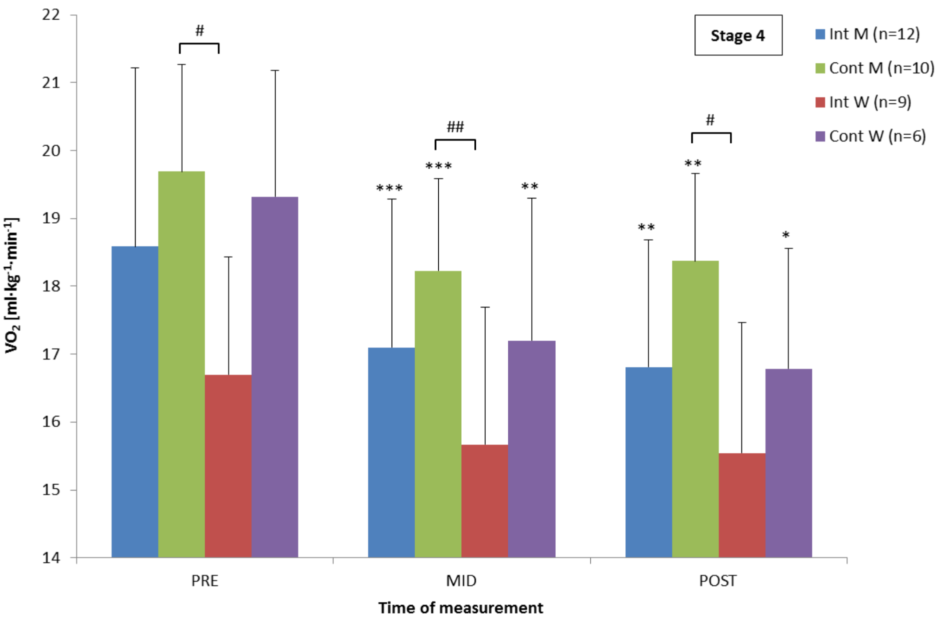

Figure 4. Oxygen consumption (VO_2) absolute values during stage 4 of the endurance capacity test. *p<0.05, **p<0.01 and ***p<0.001 refer to within-group significant differences compared to PRE. #p<0.05 and ##p<0.01 refer to significant differences between sexes.

5.2.2 Heart rate and blood lactate concentrations

During stage 2, there was no time x group interaction (F=1.079, p=0.381) or main effect for time (F=3.028, p=0.059) when adjusted for initial values. HR decreased in both female groups from PRE to POST (Int W: 103±11 vs. 94±12 bpm, p<0.01; Cont W: 105±9 vs. 94±9, p<0.01). No differences between groups were observed. MID to POST changes were not statistically different in any group (Figure 5).

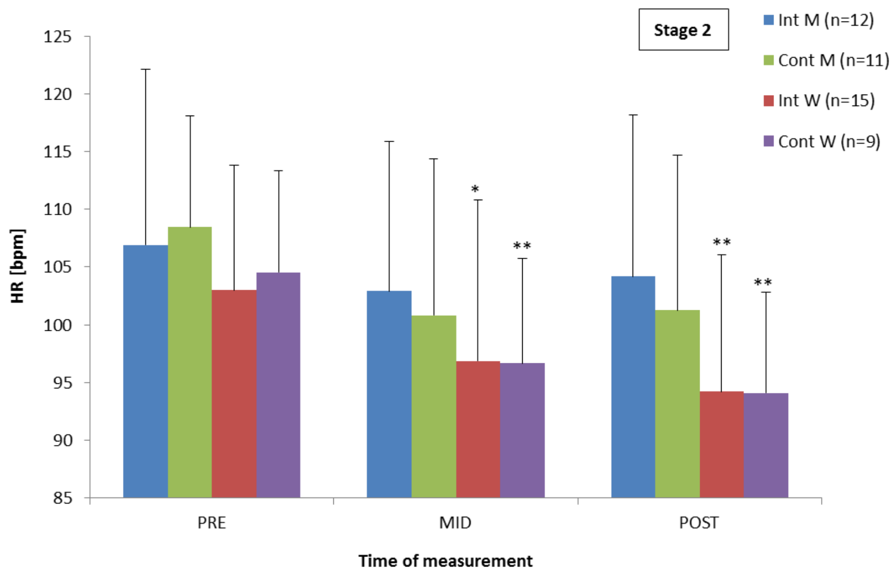

Figure 5. Heart rate (HR) absolute values during stage 2 of the endurance capacity test. *p<0.05 and **p<0.01 refer to within-group significant differences compared to PRE.

During stage 3, no time x group interaction was observed (F=2.155, p=0.55). A main effect for time was observed when adjusted for initial values at PRE (F=8.004, p<0.01). HR response was improved in all four groups from PRE to POST (Int M: 121±16 vs. 104±14 bpm, p<0.001; Int W: 116±15 vs. 94±12, p<0.001; Cont M: 119±10 vs. 101±13, p<0.01; Cont W: 119±9 vs. 94±9, p<0.001). No statistical differences between groups were observed. During this stage, changes from MID to POST were statistically significant in men (p<0.05) and women (p<0.001) (Figure 6).

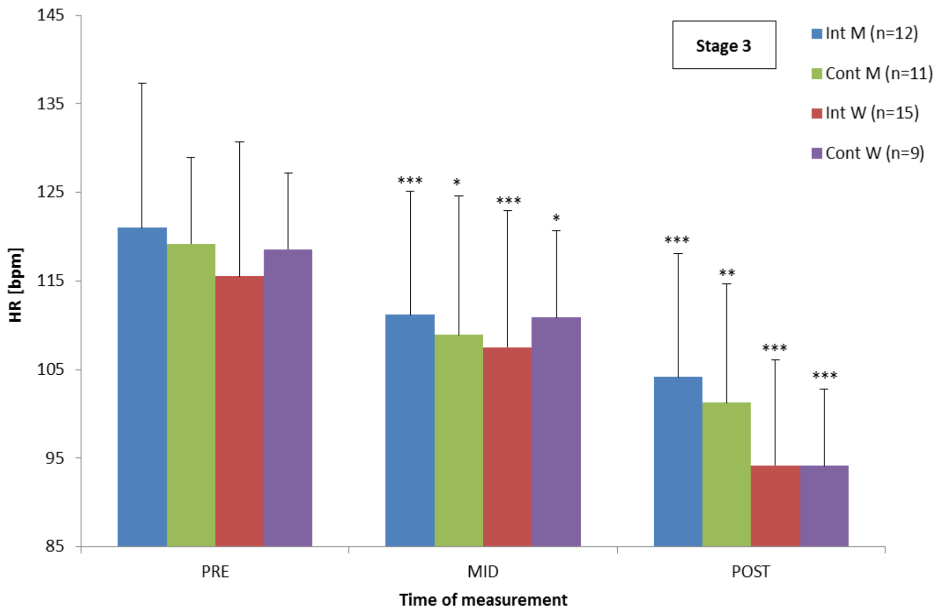

Figure 6. Heart rate (HR) absolute values during stage 3 of the endurance capacity test. *p<0.05, **p<0.01 and ***p<0.001 refer to within-group significant differences compared to PRE.

During stage 4, a main effect for time was observed (F=3.826, p=0.033) when adjusted for HR values at PRE. HR was reduced in Int M, Int W and Cont M mainly from PRE to MID measurements (Int M: 134±15 vs. 123±13 bpm, p<0.001; Int W: 121±12 vs. 112±9, p<0.01; Cont M: 129±10 vs. 118±12, p<0.01) and maintained from MID to POST. MID to POST changes were not statistically significant in any group. Changes in Cont W were not statistically significant. No differences between groups were observed (Figure 7).

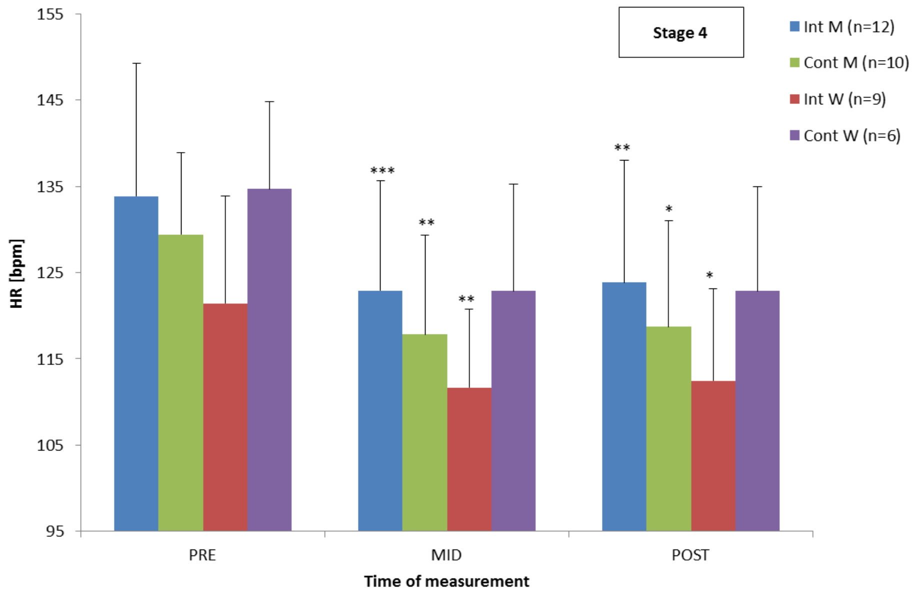

Figure 7. Heart rate (HR) absolute values during stage 4 of the endurance capacity test. *p<0.05, **p<0.01 and ***p<0.001 refer to within-group significant differences compared to PRE.

The absolute values of AUC for blood La are shown in Figure 8. The AUC for blood La concentration was reduced in both men and women of the training group (PRE to POST: Int M: 5.7±1.4 vs. 4.2±1.2 mmol·L, p<0.01; Int W: 4.3±1.4 vs. 3.3±1.2, p<0.05). No main effect for time was found when adjusted for AUC at PRE (F=1.534, p=0.228). PRE to MID changes were only significant in Int M (p<0.001). Changes in the control groups were not statistically significant. No statistical differences between groups were found.

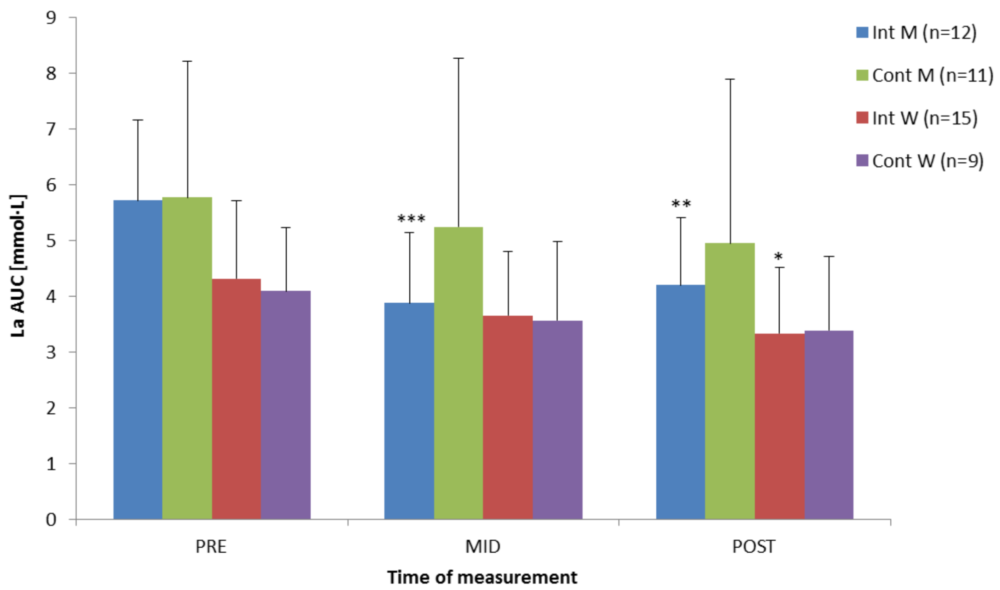

Figure 8. Area-under-the-curve (AUC) for blood lactate (La) concentration of stages 2, 3, and 4 of the endurance capacity test. *$p<0.05$, **$p<0.01$ and ***$p<0.001$ refer to significant within-group differences compared to PRE.

5.3 Endurance and strength performance before and after training

5.3.1 Estimated peak oxygen consumption (VO_{2peak})

No significant group x time interaction was observed in the estimated VO_{2peak} when adjusted for the initial level ($p=0.754$). Both men and women in the intervention group improved the estimated VO_{2peak} (PRE vs. POST: Int M: 26.2±4.2 vs. 29.9±6.5 $ml \cdot kg^{-1} \cdot min^{-1}$, $p<0.01$; Int W: 27.5±6.4 vs. 30.6±6.6, $p<0.05$), although the changes were not statistically significant when compared to the control groups. When men and women were combined together, changes in the intervention group from PRE to POST obtained more statistical power ($p<0.001$). Changes in the control groups were not statistically significant. No statistical differences were found within sexes (Figure 9).

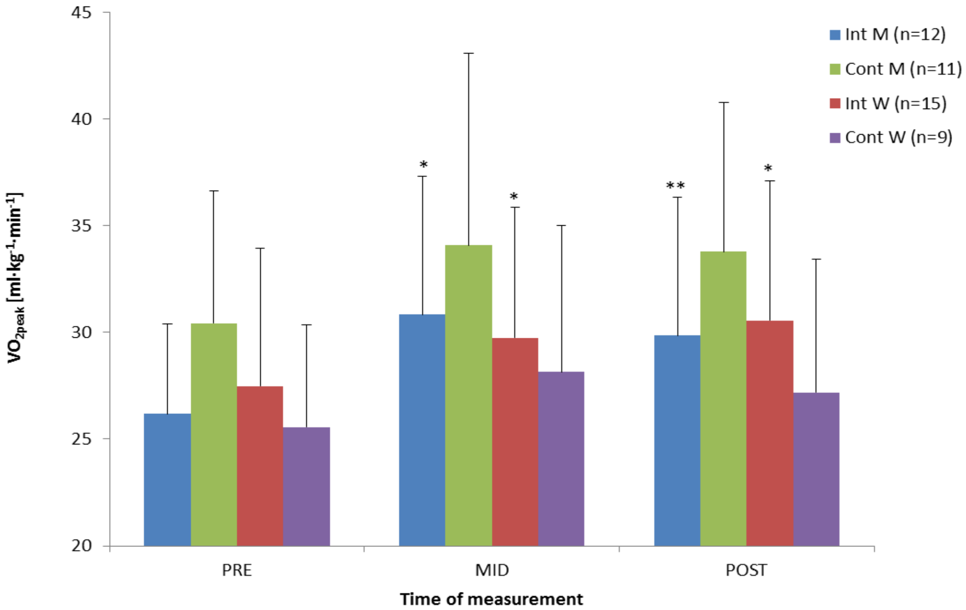

Figure 9. Estimated peak oxygen consumption (VO_{2peak}) as absolute values. *p<0.05 and **p<0.01 refer to significant within-group differences compared to PRE-measurements.

5.3.2 Leg press one repetition maximum (1RM)

A significant main effect for group was found in 1RM in dynamic leg press (F=7.387, p<0.001) when adjusted for 1RM values at PRE. Both intervention groups improved from PRE to POST measurements (Int M: 138.8±33.0 vs. 160.8±30.9 kg, p<0.01; Int W 91.3±21.3 vs. 115.6±23.1, p<0.001), whereas changes in the control groups were not statistically significant. Changes from MID to POST in the intervention groups were also statistically significant (p<0.01). 1RM was significantly lower (p<0.001) in women compared to men at PRE, MID, and POST measurements (Figure 10).

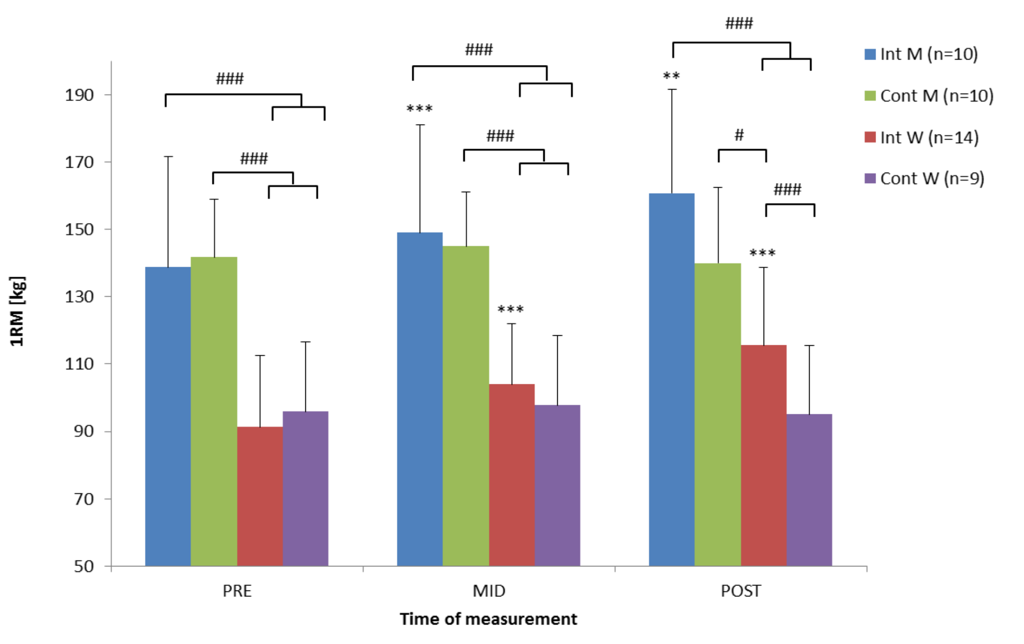

Figure 10. One repetition maximum (1RM) in dynamic leg press as absolute values. ***p<0.001 refers to significant changes within-group compared to PRE. #p<0.05 and ###p<0.001 refer to significant differences between sexes.

Relative changes in 1RM are given in Figure 11. The percent increase in 1RM from PRE to MID was greater in Int W than in Int M (13% vs. 7%, p<0.05) and than in the control groups (2%, p<0.001). PRE to MID percent changes in Int M were not statistically significant when compared to control groups. PRE to POST relative changes were greater in both Int M and Int W when compared to the control groups (p<0.001).

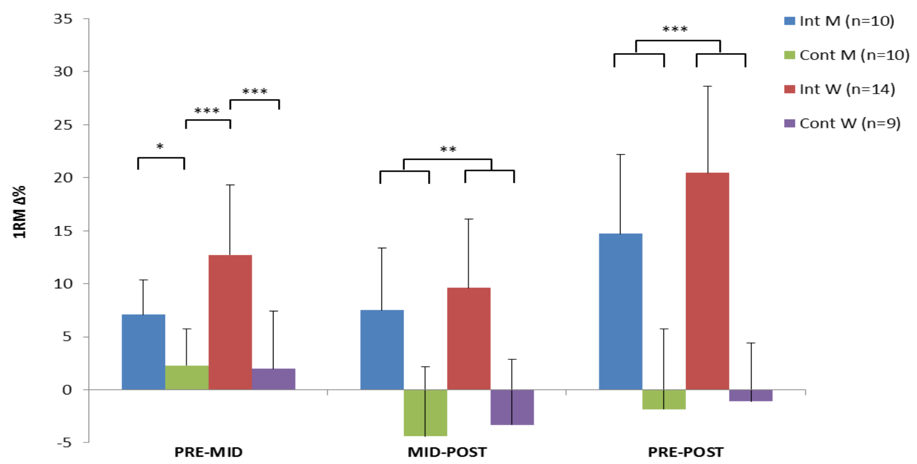

Figure 11. Changes in one repetition maximum (1RM) in dynamic leg press for all the groups. *p<0.05, **p<0.01 and ***p<0.001 refer to significant differences between groups.

5.4 Resting heart rate, hemoglobin and hematocrit before and after training

No significant changes occurred in resting heart rate in either the training or control groups from PRE to MID and POST (Table 14).

Table 14. Resting heart rate (HR_{rest}) as absolute values.

Group	HR_{rest} [bpm]		
	PRE	MID	POST
Int M (n=11)	67±13	67±12	68±9
Cont M (n=9)	69±10	64±5	66±9
Int W (n=12)	71±12	69±11	70±14
Cont W (n=7)	66±5	61±5	63±8

Values are shown as mean±SD.

Hb and Hct remained also unaltered throughout the study (Table 15). In Hb, statistical differences were only observed in absolute values between men and women at each measurement time (Int M vs. Int W & Cont W, $p<0.05$; Cont M vs. Int W & Cont W, $p<0.01$). Women had significantly lower absolute hematocrit compared to men ($p<0.05$).

Table 15. Hemoglobin (Hb) and hematocrit (Hct).

Group	Hb [g·L]			Hct [%]		
	PRE	MID	POST	PRE	MID	POST
Int M (n=12)	148±14	148±12	150±15	44±5	44±4	45±5
Cont M (n=10)	150±8	150±7	152±7	44±2	44±2	45±3
Int W (n=15)	136±10#	138±8#	138±9#	41±3#	41±3#	41±3#
Cont W (n=9)	130±5#	131±7#	132±7#	39±2#	39±2#	39±2#

Values are shown as mean±SD. #$p<0.05$ refers to significant differences compared to Int M and Cont M.

5.5 Physical activity diaries

Before the beginning of the study, no statistical differences were found between the intervention and the control groups (men and women combined) in the self-reported physical activity (Cont vs Int: 121±63 vs 94±71 min per week, $p=0.116$). Even though all were instructed to maintain their normal exercise levels, both groups increased it in the first 3 months of RT (Cont $p=0.037$; Int $p=0.028$). The control group performed more endurance exercise than the intervention group, although it did not reach statistical significance (Cont n=11 vs Int n=23: 207±100 vs 145±104 min per week, $p=0.068$). In the following 6 months, both groups slightly reduced the amount of weekly endurance exercise. The difference between groups was statistically significant (Cont n=18 vs Int n=26: 173±88 vs 112±111 min per week, $p=0.048$).

5.6 Associations between strength and endurance variables

Changes in 1RM from PRE to MID were not statistically correlated with changes in estimated VO_{2peak} (Int M, r=-0.282, p=0.4, n=11; Int W, r=-0.349, p=0.22, n=14) or in CE during stage 2 (Int M, r=-0.372, p=0.29, n=10; Int W, r=-0.312, p=0.28, n=14), stage 3 (Int M, r=-0.025, p=0.94, n=11; Int W, r=-0.34, p=0.23, n=14) or stage 4 (Int M, r=0.137, p=0.69, p=11; Int W, r=-0.497, p=0.21, n=8). Changes in 1RM from PRE to MID were negatively correlated with 1RM at PRE in the training groups (Int M, r=-0.692, $p<0.05$, n=11; Int W, r=-0.72, $p<0.01$, n=14). A negative trend correlation (r=-0.501, p=0.057, n=15) was observed in Int W between the change in estimated VO_{2peak} from PRE to POST and the initial level of VO_{2peak} at PRE.

6 DISCUSSION

The main purpose of the present study was to investigate the effect of 9 months of resistance training on cycling economy in a group of elderly men and women. It was shown that RT induced significant increases in maximal strength and endurance performance, although the changes in estimated VO_{2peak} were not statistically significant when compared to the control groups. Cycling economy was improved from PRE to MID and then maintained at POST-measurements in both training and control groups (except for Int W, changes during stage 3 were only significant from PRE to POST and during stage 4 did not reach statistical significance). No significant changes occurred in any group regarding resting heart rate, hemoglobin or hematocrit. These results may suggest that a RT program focusing on local muscular endurance (from PRE to MID) was able to induce changes in cycling economy, while a following period of hypertrophic and maximal strength training program (from MID to POST) did not stimulate further improvements. Changes in the control group may have been mediated by the increase in their endurance exercise levels as shown in the physical activity diaries.

6.1 Cycling economy

Cycling economy, referred to as oxygen consumption (per kg of body mass) at a determined exercise intensity, improved from PRE to MID in Int M, Cont M and Cont W during all stages. In Int W, reductions in VO_2 were significant during stage 2, during stage 3 only from PRE to POST, and during stage 4 did not reach statistical significance. Relative changes from MID to POST were not statistically significant in any other group.

Cycling and running economy have been shown to improve in highly trained athletes when adding RT to the regular ET (Balsalobre-Fernández et al. 2015; Rønnestad & Mujika 2014). In the elderly, few studies have investigated the effect of RT alone on economy of movement. Romero-Arenas et al. (2013) found improvements in walking economy after a circuit RT protocol. Lovell et al. (2009), in a group of 70 to 80-year-old men found a significant change at 70% of VO_{2max} but not at 40W or 50% of VO_{2max} (54-55W). These results differ somehow with our study since men in the intervention group improved cycling economy also at an intensity of 50W (45% of the estimated VO_{2peak}).

The observed results regarding HR differed between stages of the submaximal cycling test. During stage 2 relative changes from PRE to MID were only significant in the women's groups. Changes from MID to POST were not statistically significant in any group. Differently, all groups reduced HR during stage 3 from PRE to MID and POST. During stage 4, all groups improved HR from PRE to MID, although the relative changes in women of the control group did not reach statistical significance. Changes from MID to POST were not statistically significant in any group.

The fact that women in the intervention group did not improve CE and HR response during stage 4 could be explained by the small sample size. At the PRE-measurements, six women did not complete the last stage of the cycling test, while at MID only two did not, and at POST all women finished it. These increases in the completion rates also indicate a better endurance capacity following the intervention period.

Despite the improved cycling economy at 50W (stage 2) in men, the observed HR changes were not statistically significant. However, Lovell et al. (2009) found a decreased HR response at 40W and 54-55W even though oxygen consumption was not reduced. Vincent et al. (2003) also found decreased HR at min 2, 4, 6, and 8 in a group of elderly performing high intensity RT but not in a group of low intensity RT (only significant at the 2-minute time point), implying that a higher exercise intensity might be needed to improve HR response at submaximal intensities.

On the other hand, lactate concentrations were only reduced in the intervention groups. Relative changes in men were statistically significant from PRE to MID and POST, while relative changes in women were significant from PRE to MID but not from MID to POST. This reduced blood La might be due to decreased rate of lactate formation during exercise, increased rate of lactate removal, or a combination of both. Izquierdo et al. (2003) also found decreased blood lactate concentrations at submaximal workloads in elderly men after 8 weeks of RT at 40-70% 1RM using 10-15 repetitions, although no further decreases were observed after the following 8 weeks where higher intensities and lower repetitions were used.

As observed, most of the improvements in CE and submaximal HR and blood La in the intervention group occurred within the first three months of training. In the following six months, a plateau appears to occur. Two main factors may have influenced it. First, the initial fitness level of the subjects. Previously untrained subjects have shown to improve endurance capacity more than trained subjects. Thus, it may be speculated that the improvement in CE in the first three months was due to the untrained status, whereas in the following six months their submaximal endurance capacity was enhanced already to a degree where RT was not capable of inducing further improvements. Another explanation might be the type of RT protocol used. Lower loads and higher repetitions together with shorter rest periods during the first three months might have led to the observed reductions in VO_2, while higher loads and lower repetitions during the following six months might not have induced adaptations to the cardiovascular system.

The fact that the control groups also enhanced their submaximal endurance performance to the same extent as the intervention groups could be explained by the results obtained through the physical activity diaries. The results showed that subjects in the control group increased their endurance exercise in the first three months, possibly leading to endurance performance enhancements but unchanged performance in 1RM as observed in other studies following ET in the elderly (Cadore et al. 2010; Green & Crouse 1995; Izquierdo et al. 2004). The control group could be then considered as a low intensity ET group, in which mechanisms such as enhanced SV and capillarization may have mediated the improvements in CE, although blood La concentrations did not improve in this group as mentioned previously.

6.2 Endurance and strength performance

6.2.1 Estimated VO_{2peak}

Both men and women in the intervention group increased their estimated VO_{2peak} (13 and 7%, respectively) following 3 months of RT focusing on local muscular endurance and then declined (men: -6%) or improved (women: 2%) after the following 6 months of RT focusing on hypertrophy and maximal strength, leading to gains from PRE to POST of 11 and 10%, respectively. The changes were not significant when compared to the control groups.

These observed increases in VO_{2peak} are similar as in previous studies investigating the effect of RT on VO_{2max} in the elderly (Hepple et al. 1987; Hagerman et al. 2000; Okazaki et al. 2002; Lovell et al. 2009) and somewhat smaller than in the studies by Vincent et al. (2002) and Wieser & Haber (2007). However, there are also some studies showing no significant changes in VO_{2max} after RT programs with similar durations, frequencies and intensities as the ones mentioned previously (Frontera et al. 1990; Ades et al. 1996; Cadore et al. 2010).

Vincent et al. (2002) compared a group of healthy active older people performing RT at 80% of 1RM with another group performing RT at 50% of 1RM and found an increase in VO_{2peak} of 20 and 24%, respectively. Wieser & Haber (2007) observed a 15% increase after 12 weeks of RT. In these two studies, the initial VO_{2peak} of the subjects was 20 and 19 ml/kg/min. In our study, however, the initial level ranged from 26 to 30 ml/kg/min (not statistically significant differences). These differences at baseline may have led to smaller gains in our study since also Ozaki et al. (2013) reported in their review an influence of the initial level on the improvement in VO_{2max}. They proposed that subjects with an initial VO_{2max} lower than 25 ml/kg/min are able to experience greater changes following a period of RT. Although not statistically significant, a negative trend was found between the estimated initial level of VO_{2peak} and the relative change from PRE to POST in VO_{2peak} in women of the present intervention group.

The same authors (Ozaki et al. 2013) also reported that training volume, intensity or rest periods were not related to the relative change in VO_{2max}. However, the included studies had rest periods between 1.5 and 2 min. In our study, rest periods of 30 s and 1 min were used in the first three months of the training program. It might be hypothesized that those short periods allowed for a greater cardiovascular stimulus, which could potentially influence the change in VO_{2peak}. This is supported by the fact that relative changes in VO_{2peak} were not correlated with changes in muscle strength.

6.2.2 Leg press 1RM

Resistance training has previously been shown to lead to strength performance enhancements in elderly subjects (Liu & Latham, 2009; Peterson et al. 2010; Steib et al. 2010; Silva et al. 2014). As expected, both men and women in the intervention group improved their leg press 1RM (PRE-MID: 7 & 13%; PRE-POST: 15 & 20%, respectively).

The average increases in muscle strength range from 20 to 70% in studies using intensities from 40 to 85% of 1RM, one to three weekly sessions and durations of 6 to 24 weeks (Cadore et al. 2014). In the meta-analysis performed by Peterson et al. (2010), 47 studies were included and a 33% increase in knee extension strength was observed. These authors reported that higher intensity RT programs (above 70-80% 1RM) produce greater strength improvements, as also noted by Liu & Latham (2009). Silva et al. (2014) reported in their meta-analysis higher effect sizes for studies with longer durations (6 to 13 months). The magnitude of the observed muscle strength increases in our study was, therefore, somewhat smaller than in other studies of similar characteristics. This was also surprising since it has been shown that in untrained subjects, strength gains in short programs are mainly due to neural adaptations. It is in longer duration programs where hypertrophic adaptations occur too, leading to further strength enhancements (McComas 1994).

It has been shown that in untrained subjects, at least one familiarization session is required in order to eliminate the learning effect and achieve the real 1RM in the following testing session. Levinger et al. (2009) demonstrated that one familiarization session might be enough before assessing 1RM in untrained middle-age subjects. In untrained elderly subjects, Phillips et al. (2004) showed that 3 familiarization sessions are required for a high reliability, while Ploutz-Snyder & Giamis (2001) reported that they should perform 8-9 sessions to increase the consistency of the 1RM measurement. However, this is not very feasible in studies where the aim is to investigate the effect of RT since a long familiarization period would require more time and would already induce neural adaptations in the participants. For this reason every subject performed one practice session.

The observed relative change in the first three months was significantly higher in women compared to men. This was rather surprising since previous studies comparing elderly men and women have shown similar relative strength increases (Häkkinen et al. 1998; Ivey et al. 2000; Leenders et al. 2013; Tracey et al. 1999) or greater increases in men (Bamman et al. 2003). However, in our study the relative changes in 1RM were not statistically significant between men and women after the 9-month RT, although women maintained the trend of the first three months and obtained greater relative increases than men.

A negative correlation was found between the 1RM at PRE and the relative change in 1RM from PRE to MID. This corresponds to other studies that have reported an effect of the subject's initial level of strength on the expected improvement in strength following RT (Häkkinen 1985; Pollock et al. 1998).

6.3 Mechanisms underlying the improvements in CE and estimated VO_{2peak}

Changes in maximal strength were not statistically correlated with changes in CE, meaning that the increase in strength of the leg muscles did not induce the observed reduction in oxygen consumption at those submaximal intensities. Therefore, other mechanisms might have occurred.

Resting heart rate, hemoglobin and hematocrit were measured in our study in order to examine the possible influence of resistance training on the cardiovascular system (cardiac function and oxygen-carrying capacity of blood) in the elderly. All these parameters remained unaltered throughout the intervention period in all groups, and only absolute Hb concentrations and Hct percentages were significantly different between genders.

Previous research investigating the effects of RT on HR_{rest} has shown conflicting results. The observed absence of change in HR_{rest} concurs with other similar studies (Beltran Valls et al. 2014; Gerage et al. 2013; Vincent et al. 2003). Contrary to this, few studies have shown reductions (Williams et al. 2013) and even increases (Cononie et al. 1991). The improvement in the estimated VO_{2peak} and in cycling economy especially in the first three months of our study where RT with low loads and short rest periods were used could suggest that the program design was similar to an ET program. And, thus, it could be hypothesized that a reduction in HR_{rest} might be observed. However, even if some studies regarding ET have shown declines in HR_{rest} (Ehsani et al. 1991; Blumenthal et al. 1989; Stratton et al. 1994), some others have reported no changes (Fabre et al. 1997; Perini et al. 2002). Therefore, our results are not surprising. It appears that the RT program did not induce a sufficient stimulus to the cardiovascular system in order to improve HR_{rest}.

Other central adaptations of the cardiovascular system shown to be improved after endurance training are Hb and Hct, which increase the oxygen transport capacity, and thus, improve the aerobic fitness (McArdle et al. 2010, 459). In the elderly, only one study regarding ET has been performed to date (Pickering et al. 1997). The authors found a lowered Hb concentration and Hct in response to training due to hemodilution (expanded plasma volume). Hemoglobin concentration did not change after 3 months of RT (Frontera et al. 1990). In the same manner as with HR_{rest}, the unchanged [Hb] and Hct in our study seems to indicate that the RT program did not induce central adaptations on the cardiovascular system.

These data suggest that the observed improvements in cycling economy and estimated VO_{2peak} were due to other central and/or peripheral adaptations. According to Spina et al. (1991), changes in VO_{2max} after ET were accounted for by Q_{max} (the product of heart rate and stroke volume) and a-vO_2 diff increases in men, meaning a better cardiac function and a better oxygen extraction from the blood. In women, VO_{2max} changes were only accounted for by an increased a-vO_2 diff. After 16 weeks of RT, Lovell et al. (2009) found a significant increase in SV at 40W (about 40% VO_{2max}), but not at 50 and 70% VO_{2max} and reported the importance of the change in a-vO_2 diff for improving VO_{2max}.

Capillary density and enzyme activity increases have been shown after ET in the elderly (Coggan et al. 1992; Hepple et al. 1997). There seems to be a relationship between capillary supply and VO_{2peak} in the elderly. The evidence appears to be quite clear regarding ET, while there is still some controversy regarding the effects of RT on muscle capillarization (Harris 2005). Hepple et al. (1997) and Frontera et al. (1990) reported RT-induced increases in mitochondria enzyme activity and capillary-to-fiber ratio in old subjects.

Other possible factors that might improve VO_{2max} are increases in muscle mass and blood flow to the exercising muscles (Ozaki et al. 2013). All of these adaptations might have occurred in the RT protocol performed during the first three months of our study, since high repetitions with low loads and short breaks were planned for an improvement in the local muscular endurance.

6.4 Limitations of the study

The present study compared a group of elderly performing resistance training for 9 months to a control group that was instructed to maintain their regular physical activity levels. However, the control group increased the amount of endurance exercise, possibly inducing the observed improvements in cycling economy. Another limitation of the study is the absence of a familiarization session for the submaximal cycling test, which might have affected the results at month 3.

Regarding the VO_{2peak} results, caution must be paid since it was estimated from the submaximal cycling test data. This implies that the values obtained might not be as accurate as if a maximal exercise test until exhaustion had been performed. However, performing this kind of test requires a doctor, increasing the cost of the investigation and making it less doable. A submaximal test was, therefore, a more practical way to answer the questions of this research.

7 CONCLUSIONS

The current study showed that a resistance training program focusing on local muscular endurance led to cycling economy improvements in a group of elderly men and women, although a further period of resistance training focusing on hypertrophy, maximal strength and explosive training did not induce further improvements. On the other hand, the control group increased their regular endurance exercise, possibly leading to the observed improvements in cycling economy. Data did not show differences between groups.

Our findings provided some evidence to suggest that maximal endurance and strength performance are also increased after resistance training. Estimated peak oxygen consumption was enhanced in the first period and remained unchanged until the end of the intervention. No differences between genders were found. Leg press one repetition maximum was enhanced throughout the training period. Men's strength performance was greater than women's, although relative changes in the first three months were greater in women. Changes in the control group were not statistically significant.

Collectively these findings might have important implications. Aging is a process linked to losses in muscle mass and strength, cardiovascular fitness, etc. Our results suggest that resistance training is not only able to induce improvements in muscle strength of elderly people, but also might improve maximal and submaximal endurance performance. All of these could lead to benefits in the daily life where submaximal efforts such as climbing the stairs and raising from a chair take place.

Therefore, a resistance training protocol focusing on local muscular endurance (14-20 repetitions, 40-60% 1RM and 30-60s rest periods) could be recommended as an efficient training method for improving cycling economy as well as maximal strength and endurance performance in older men and women.

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