Efficiency of twice weekly concurrent training in trained elderly men

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A B S T R A C T

This study compared the effects of different weekly training frequencies on the cardiovascular and neuromuscular adaptations induced by concurrent training in previously trained elderly. After 20 weeks of combined strength and endurance training, twenty-four healthy elderly men (65 ± 4 years) were randomly placed into two frequency training groups: strength and endurance training performed twice a week (SE2, n = 12); or, strength and endurance training performed three times per week (SE3, n = 12). The interventions lasted 10 weeks and each group performed identical exercise intensity and volume per session. Before and after the exercise training, one maximum repetition test (1RM), isometric peak torque (PT), maximal surface electromyographic activity (EMG), as well as muscle thickness (MT) were examined. Additionally, peak oxygen uptake (VO2peak), maximum aerobic workload (Wmax), first and second ventilatory thresholds (VT1 and VT2) were evaluated. There were significant increases in upper and lower-body 1RM, MT, VO2peak, VT1 and VT2, with no differences between groups. There were no changes after training in maximal EMG and isometric peak torque. Wmax was improved only in SE3. After 10 weeks of training, twice weekly combined strength and endurance training leads to similar neuromuscular and cardiovascular adaptations as three times per week, demonstrating the efficiency of lower frequency of concurrent training in previously trained elderly men.

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1. Introduction

Biological aging is associated with declines of different physiological systems, including the neuromuscular system, through the loss of strength, power and muscle mass (Aagaard et al., 2007; Izquierdo et al., 2001), as well as the cardiovascular system, which presents important declines in peak oxygen consumption (VO2peak) (Astrand et al., 1973). These reductions are directly related to loss of mobility in older individuals, reducing the independence and quality of life for this population (Lauretani et al., 2003). Regular physical activity is a cornerstone intervention to counteract many age-associated diseases and increase functional independence (ACSM, 2009). Among the main benefits of physical activity in the elderly, increased VO2peak as a result of endurance training (Cadore et al., 2012; Karavirta et al., 2011), may confer greater independence for older individuals to perform daily activities such as climbing stairs, sit/stand and balance themselves (Steib et al., 2010).

A combination of strength and endurance interventions (i.e., concurrent training) seems to be the most effective strategy to improve both neuromuscular and cardiovascular functions in elderly (Cadore et al., 2012; Izquierdo et al., 2004; Wood et al., 2001). However, excessive volumes of both strength and endurance training may compromise the neuromuscular adaptations in older subjects (Cadore et al., 2010). In addition, it has been shown that different strength training frequencies (1, 2 or 3 sessions per week) induced similar muscle strength gains in untrained older adults (DiFrancisco-Donoghue et al., 2007; Taaffe et al., 1999). Recently, Holviala et al. (2012) have shown that strength training performed twice a week promoted greater increases in muscle strength when compared with a frequency of once a week, after 21 weeks of training in previously strength trained elderly. Therefore, the training status (i.e., trained or untrained) may be related to the strength training dose–response in the elderly. In regard to the concurrent training, only one study has compared different volumes of training in elderly. Izquierdo et al. (2004) observed no differences in strength gains between strength training alone (twice a week) and concurrent training (performing strength exercises on one

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day, and endurance exercise on the other day). In addition, these authors reported similar cardiovascular adaptations between endurance training alone (twice a week) and the concurrent training group. Notwithstanding, it remains poorly understood whether previously concurrent trained subjects would present differential magnitude of neuromuscular and cardiovascular adaptations to distinct weekly frequency in sessions of concurrent training.

Since the knowledge of weekly frequency of concurrent training in trained elderly could contribute to optimize the exercise prescriptions, the purpose of the present study was to compare the effects of different training frequencies (i.e., 3 vs. 2 sessions per week) during concurrent training on neuromuscular and cardiovascular adaptations in previously trained elderly men. We hypothesized that both training groups would obtain similar neuromuscular adaptations. Further, to analyze the differences in training prescriptions more comprehensively, we evaluated cardiorespiratory variables, hypothesizing that greater exercise volume (three times per week) would promote greater cardiovascular gains.

2. Methods

2.1. Subjects

Twenty-four healthy elderly men (mean 64 years, range 60–75 years), previously engaged in a regular and systematic exercise program for the last 5 months, volunteered for the study after completing an ethical consent form. Subjects were carefully informed about the design of the study with special information about possible risks and discomforts. Subsequently, subjects were randomly placed into two groups: strength and endurance training performed twice a week (SE2, n = 12); and, strength and endurance training performed three times per week (SE3, n = 12). The study was conducted according to the Declaration of Helsinki and the protocol was approved by the local Institutional Review Board. Exclusion criteria included any history of neuromuscular, metabolic, hormonal and cardiovascular diseases (except controlled stage 1 hypertension). Subjects were not taking any medication with influence on hormonal and neuromuscular metabolism and were advised to maintain their normal dietary intake throughout the study. Medical evaluations were performed using health questionnaire and maximal exercise test with 12-lead electrocardiography (ECG). The physical characteristics of subjects are shown in Table 1. Body mass and height were measured using an analog scale (resolution of 0.1 kg) and stadiometer (resolution of 1 mm), respectively (Asimed, Camarate, Portugal). Body composition was assessed using skinfold technique (LANGE, Cambridge, United Kingdom). A seven-site skinfold equation was used to estimate body density (Jackson and Pollock, 1978) and body fat was subsequently calculated using the Siri equation (Siri, 1993).

2.2. Experimental design

In order to compare the physiological effects of different concurrent training volumes in trained elderly men, we assessed a group of subjects who previously performed 12 weeks of periodized strength and endurance training program, which has been previously described (Cadore et al., 2012). After these 12 weeks of high intensity and volume of concurrent training, the elderly men performed additional 8 weeks of training at constant volume and intensity (25 min of endurance training at self-selected intensity + 2 sets of 10–12 repetitions of strength training using the load correspondent to 15 repetition maximum), aimed to maintain the neuromuscular and cardiovascular adaptations achieved in the first 12 weeks. Throughout both of these training periods the frequency was 3 times per week. After that, subjects performed the intervention of 10 weeks of periodized concurrent training with either twice or thrice sessions per week. Despite the different number of training sessions per week (i.e., 3 × 2 sessions per week), both groups performed the same intensity and volume per session of concurrent training. Thus, in the present study, we investigated the efficiency of 2 sessions of concurrent training when compared with 3 sessions in previously trained elderly men. Before and after the last 10 weeks of training, the subjects were evaluated using variables related to neuromuscular and cardiovascular adaptations. The stability and reliability of the performance variables are reported elsewhere (Cadore et al., 2012, 2013). Each specific test at pre- and post-intervention was overseen by the same investigator, who was blinded to the training group, and was conducted on the same equipment with identical subject/equipment positioning. Experimental evaluations were carried out at the same time of day throughout the study, and different tests were conducted on separate days to avoid fatigue.

2.3. Maximal dynamic strength

Maximal dynamic strength was assessed using the 1RM on bilateral elbow flexors and bilateral knee extensors. The subjects warmed up for 5 min on a cycle ergometer, stretched all major muscle groups, and performed specific movements with 1 set of 15 repetitions with light load (30% of the first test load) in exercise tests. Maximal load was determined with no more than five attempts with a 4-min recovery between sets (Silva et al., 2012). Each contraction (concentric and eccentric) lasted 2 s, controlled by an electronic metronome (Quartz, CA, USA). The test–retest reliability coefficients (ICC) were 0.96 for both exercises.

2.4. Muscle thickness

After at least 72 h without any vigorous physical activity, subjects initially rested during 15 min before the procedures, which occurred in a temperature-controlled room and supine position. The muscle thickness (MT) was measured using B-mode ultrasound (Philips, VMI, Belo Horizonte, MG, Brazil). A 7.5-MHz probe with a water-soluble transmission gel was placed on the skin perpendicular to the tissue interface. The images were digitalized and after they were analyzed in software Image-J (National Institutes of Health, USA, version 1.37). The subcutaneous adipose tissue–muscle interface and the muscle–bone interface were identified, and the distance from the adipose tissue–muscle interface was defined as MT. The MT images were determined in the lower-body muscles vastus lateralis (VL), vastus medialis (VM), vastus intermedius (VI) and rectus femoris (RF). The measurement for the VL was taken at midway between the lateral condyle of the femur and greater trochanter (Kumagai et al., 2000), whereas the measurement for the VM was taken at 30% of the distance between the lateral condyle of the femur and the greater trochanter (Korhonen et al., 2009), yet the measurements for the VI and RF were measured as 60% the distance from the greater trochanter to the lateral epicondyle and 3 cm lateral to the midline of the anterior thigh (Chilibeck et al., 2004). In upper-body limbs, MT were obtained in the biceps brachii (BB) and brachialis (BR) muscle mass. The site to elbow flexor measurement was at 40% of the distance from the lateral epicondyle to acromion process in scapula (Miyata et al., 2002). To ensure identical placement in subsequent tests, the right thigh and arm of each subject were mapped for the position of anatomical points and small angiomas by

Table 1
Subjects' characteristics pre- and post-training. Mean ± SD.

<table>
<thead>
<tr>
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<th>Pre-training</th>
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<td>SE2 (n = 11)</td>
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<tr>
<td>Age, year</td>
<td>63.2 ± 2.2</td>
<td>63.4 ± 2.2</td>
<td>65.7 ± 5.7</td>
<td>65.9 ± 5.7</td>
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<tr>
<td>Height, m</td>
<td>1.75 ± 0.6</td>
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<td>1.69 ± 0.3</td>
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<tr>
<td>Body mass, kg</td>
<td>81.4 ± 10.5</td>
<td>80.9 ± 10.2</td>
<td>76.1 ± 6.3</td>
<td>75.9 ± 7.6</td>
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<tr>
<td>% body fat</td>
<td>27.8 ± 2.5</td>
<td>25.8 ± 3.7</td>
<td>26.2 ± 2.9</td>
<td>25.2 ± 2.6</td>
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<tr>
<td>SE3 (n = 12)</td>
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<td>63.4 ± 2.2</td>
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Strength–endurance twice a week group (SE2); strength–endurance three times a week group (SE3); no significant differences between training groups.
marking on transparent paper (Cadore et al., 2012). The MT test–retest reliability coefficients (ICC) were 0.92 for BB, 0.93 for BR, 0.94 for VL, 0.91 for VM, 0.92 for VI and 0.95 for RF.

2.5. Isometric and isokinetic peak torque

The isometric knee extension test was measured using a Cybex Norm II Isokinetic Dynamometer (Lumex Co., Ronkonkoma, NY, USA), calibrated according to manufacturing standards prior to each day of testing. The warm up consisted of 15 submaximal isokinetic knee extension and flexion repetitions at 120°·s⁻¹. The subjects were maintained in position after adjustment of the height of the dynamometer and the length of the support, allowing the knee joint of the subjects to be aligned with the axis of rotation of the dynamometer. Each subject was stabilized at the chest, waist, and thigh with a strap. A shin strap was secured to the lower leg proximal to the malleoli; and the test was performed on the dominant limb (Silva et al., 2012). Isometric peak torque was determined during a 5-s maximal isometric knee extension at a knee angle of 60° full extension (≥ 0°). Three maximal 5-s isometric contractions were performed with 3-min rest intervals between each contraction. The contraction with the highest torque value was used in data analysis. The test–retest reliability coefficient (ICC) was 0.94 in the dynamometer test.

2.6. EMG measurements

During the isometric peak torque test, the maximal neuromuscular activity of agonist muscles was evaluated using surface electromyography (root mean square values = RMS) in the vastus lateralis and rectus femoris. Electrodes were positioned on the muscular belly in a bipolar configuration (20 mm interelectrode distance) in parallel with the orientation of the muscle fibers, as previously described (Cadore et al., 2013). Shaving and abrasion with alcohol were carried out on the muscular belly, in order to maintain the interelectrode resistance below 2013). Shaving and abrasion with alcohol were carried out on the mus-

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2.7. Peak oxygen consumption, maximum aerobic workload and ventilatory thresholds

Incremental testing on a cycle ergometer (Cybex, Ronkonkoma, NY, USA) was conducted in order to determine the VO₂peak maximal workload (Wmax), first (VT1) and second (VT2) ventilatory thresholds, and heart rate at VT2 (HRVT2). During the tests, subjects initially cycled with a 25 W load, which was progressively increased by 25 W every 2 min, while maintaining a cadence of 70–75 rpm, until exhaustion (Izquierdo et al., 2004). The test was halted when subjects were no longer able to maintain a cadence of over 70 rpm. All the incremental tests were supervised by a physician. The breath-by-breath expired gases were analyzed by a metabolic cart (CPX/D, Medical Graphics Corporation, St. Paul, MN, USA). VT1 and VT2 were determined through the ventilation curve and confirmed by curves of ventilatory equivalents for O₂ (VE/VO₂) and CO₂ (VE/VCO₂), respectively (Wasserman et al., 1973). Three experienced physiologists determined the corresponding points by visual inspection in a blinded procedure. The maximum VO₂ value (ml·kg⁻¹·min⁻¹) obtained close to exhaustion was considered as VO₂peak. The maximum test was considered valid if at least 2 of the 3 listed criteria were met: 1) maximum heart rate predicted by age was reached (220 – age); 2) impossibility of continuing to pedal at a minimum velocity of 70 rpm; and 3) respiratory exchange rate greater than 1.1 was obtained (Howley et al., 1995; Izquierdo et al., 2004). For the data analysis, curves of exhaled and inhaled gases were smoothed by visual analysis using the Cardiorespiratory Diagnostic Software Breeze Ex version 3.06. Heart rate (HR) was measured using a Polar monitor (model FS1, Shanghai, CHI). The test–retest reliability coefficients (ICC) were 0.88 to VO₂peak and Wmax, as well as 0.85 to VT1 and VT2.

2.8. Concurrent training program

Both groups took part in a concurrent training program that lasted 10 weeks. They performed both strength and endurance training on the same session, in which the strength exercises were performed first and were immediately followed by the endurance exercise. Training groups performed the same exercise intensity and volume per session, and were different in the number of training sessions per week. The SE2 group trained on Mondays and Fridays, and the subjects of SE3 group trained on Mondays, Wednesdays and Fridays. All the training sessions were carefully supervised by at least 2 experienced personal trainers. The strength training program included nine exercises (inclined leg press, knee extension, leg curl, seated row, biceps curl, bench press, inverted fly, triceps curl and abdominal exercises) performed until failure (repetition maximum — RM). These exercises were chosen to emphasize both major and minor muscle groups, using single as well multi-joint exercises, based in the recommendation of ACSM (2009). During the first three weeks, subjects performed three sets of 12-10 RM, progressing to 10-8 RM (weeks 4–6) and finalizing with three sets of 8-6 RM (weeks 7–10). In each set the workload was adjusted when repetitions performed were either under or above the repetitions established (Cadore et al., 2010). The recovery between sets lasted 120 s. The endurance training program was performed on a cycle ergometer. Each session lasted 30 min and had the intensity individually monitored according to the HRVT2, using a range between 85 and 95% of the HRVT2. The whole concurrent training periodization is shown in Table 2.

2.9. Statistical analysis

Results are reported as mean ± SD. Normal distribution and homogeneity parameters were checked with Shapiro–Wilk and Levene tests respectively. The training-related effects were assessed using a two-way Analysis of Variance (ANOVA) with repeated measures (group × time). When the interaction was significant, the main factors group and time were tested again using t tests. Significance was accepted when α = 0.05 and the SPSS statistical software package (version 17.0) were used to analyze all data. On the basis of a previous study with concurrent training performed in our laboratory (Cadore et al., 2012), we estimated that a sample size of 11 individuals would be required to identify a difference of approximately 25% levels of muscle strength with a statistical power of 85%, for an α of 0.05.

<table>
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<th>Table 2</th>
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<td><strong>Strength and endurance training periodization.</strong></td>
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<tr>
<td><strong>Strength training</strong></td>
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<td><strong>Sets per exercise</strong></td>
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<td>Weeks 1–3</td>
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<td>Weeks 4–6</td>
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<td>Weeks 7–10</td>
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RM: maximum repetitions; HRVT2: heart rate at second ventilatory threshold; Rep.: repetitions.
3. Results

One participant dropped out during the training period due to personal issues. At the end of the study, the number of subjects in each group was: SE2 = 11; and, SE3 = 12. All subjects performed at least 90% of training with no difference between groups in training compliance (mean SE2: 19.7 of 20 sessions and mean SE3: 29.1 of 30 sessions). The overall experimental design is demonstrated in Fig. 1, which illustrates the concurrent training effects on 1RM, muscle thickness, and VO2peak (Fig. 1).

3.1. Maximal dynamic strength

At baseline, there were no differences between groups in upper (elbow flexors) and lower-body (knee extensors) 1 RM values. After training, there were increases (p < 0.001) in upper-body 1RM (SE2: 10.5 ± 4.6%; and, SE3: 7.1 ± 4.8%) and lower-body 1RM (SE2: 22.5 ± 9.5%; and, SE3: 19.7 ± 8.9%). No significant differences between groups were observed in the training-induced changes in upper and lower-body 1RM values (Fig. 2).

3.2. Muscle thickness

At baseline, there were no differences between groups in lower-body (VL, RF, VM and VI) and upper-body muscle thickness (BB and BR). After training, there were increases (p < 0.001) in VL (SE2: 5.0 ± 3.5%; and, SE3: 6.3 ± 3.2%), RF (SE2: 4.6 ± 2.4%; and, SE3: 7.8 ± 5.5%), VI (SE2: 8.8 ± 5.9%; and, SE3: 12.9 ± 9.0%), and VM muscle thickness (SE2: 3.5 ± 2.7%; and, SE3: 4.1 ± 2.8%). In the upper-body muscle thickness, there were increases (p < 0.001) in BB (SE2: 4.6 ± 3.6%; and, SE3: 2.7 ± 1.0%) and BR (SE2: 10.2 ± 9.3%; and, SE3: 10.9 ± 5.6%). No significant differences between groups were observed in the training-induced changes in the lower and upper-body muscle thickness variables (Fig. 3 and Table 3).

3.3. Isometric peak torque

At baseline, groups did not differ in isometric peak torque values. No significant differences between groups were observed in the training-induced changes in isometric peak torque (Table 3).

3.4. EMG measurements

At baseline, there were no differences between groups in the maximal neuromuscular activity (maximal EMG amplitude) of VL and RF (Table 3). After training, there were no changes in the maximal neuromuscular activity of VL and RF.

3.5. Peak oxygen consumption, maximum aerobic workload and ventilatory thresholds

At baseline, there were no differences between groups in VO2peak, Wmax, VT1 and VT2. After training, both groups presented similar
increases in VO2peak (SE2: 22.1 ± 10.7%; and, SE3: 14.2 ± 10.8%, p < 0.001). In Wmax there was significant time vs. group interaction (p < 0.01), in which changes were observed only in SE3 (13.3 ± 9.6%, p < 0.01). Both VT1 (SE2: 18.3 ± 11.9%; and, SE3: 6.4 ± 18.2%) and VT2 (SE2: 13.9 ± 16.7%; and, SE3: 4.6 ± 14.4%) increased after training (p < 0.05), with no differences between groups (Table 4).

4. Discussion

To our knowledge, this was the first study designed to compare in previously trained elderly groups the cardiovascular and neuromuscular effects of low-frequency (2 · wk−1) combined strength and endurance training with those attained in a high-frequency training approach (3 · wk−1). The main findings of the present study were the similar improvements in maximal muscle strength, MT and VO2peak induced by concurrent training performed either 2 or 3 sessions per week in trained elderly men, whereas the maximal power on a cycle ergometer was improved only with 3 sessions per week. The present observations suggest the efficiency of concurrent training performed twice a week to enhance the overall physical fitness in previously trained elderly men. These findings may have important practical relevance for optimal construction of cardiovascular and neuromuscular training programs for older men since muscle strength, muscle power and endurance performance are important health-related fitness components in this population.

The reduction in muscle strength and endurance is a hallmark of the aging process (Aagaard et al., 2007; Astrand et al., 1973). In this regard, different types of exercise training benefit the older population by inducing increases in VO2peak, muscle strength and functional capacity (Cadore and Izquierdo, 2013). However, such pieces of evidence have been primarily shown in previously untrained subjects (Cadore et al., 2010; Izquierdo et al., 2004; Karavirta et al., 2009, 2011; Sillanpää et al., 2008, 2009; Wood et al., 2001). A unique characteristic of the present study was the comparison in elderly men of different weekly frequencies in a previously 20 week trained group. Therefore, we chose to test the assessment of the frequency of exercise sessions due to its common manipulation in exercise programs. Both SE2 and SE3 groups kept improving their maximal values of strength, muscle mass, and VO2peak at magnitudes comparable to those observed in the early-phase of training (Cadore et al., 2012) as well as to other studies investigating concurrent training adaptations in untrained elderly (Cadore et al., 2010; Izquierdo et al., 2004; Karavirta et al., 2009, 2011; Sillanpää et al., 2008; Wood et al., 2001).

Few studies investigated the effects of different training frequencies in elderly populations (DiFrancisco-Donoghue et al., 2007; Holviala et al., 2012; Taaffe et al., 1999). Taaffe et al. (1999) observed similar 1RM strength improvements induced by different frequencies of training (1 vs. 2 vs. 3 sessions per week) in untrained older adults. Holviala et al. (2012) showed that a twice-a-week training promoted greater strength...
gains than once-a-week, suggesting that a minimum volume may be necessary to improve maximal strength in trained subjects. In the present study, both SE2 and SE3 weekly frequencies promoted similar neuromuscular changes, indicating the efficiency of concurrent training performed twice a week in trained elderly men. It is possible that training 12 sets per week (SE2) achieved a threshold stimulus for muscle strength and mass gains. More interestingly, our results indicated that adding 6 sets (SE3) in the weekly exercise program increased the maximal aerobic power, but did not further induce further improvements neither in muscle variables nor in VO2peak of trained older subjects. In addition, it may be speculated that any possible advantages obtained with the greater weekly volume performed by SE3 group was compensated by lower recovery time between sessions (~48 h) and potentially limited muscle recovery in this group when compared with SE2 group (~72 h).

The absence of changes in maximal EMG amplitude of VL and RF muscles observed in both groups may be explained by the fact that EMG changes reflect neural adaptations, usually observed in early phases of training (Moritani and DeVries, 1979). In fact, the subjects of the present study had their maximal EMG amplitude improved in their first 12 weeks of training (Cadore et al., 2013). In addition, the EMG data were assessed during the isometric peak torque test, which presented no changes in our study.

It has been suggested that a minimum of 3 sessions per week of endurance training is necessary to increase VO2peak in healthy middle-aged and older adults (ACSM, 2009). In older adults, positive effects of concurrent training on VO2peak have been shown in previous studies with both twice (Izquierdo et al., 2004; Sillanpää et al., 2008) and thrice a week programs (Cadore et al., 2010, 2012). In the present study, both SE2 and SE3 groups showed similar increases in VO2peak, VT1 and VT2, but only SE3 enhanced the Wmax. These results suggest that higher concurrent training volumes might be necessary to elicit increases in maximal aerobic power. However, the similar increases observed in the VO2peak, VT1 and VT2 in both weekly frequencies highlight the efficiency of a concurrent training program performed twice a week to promote cardiovascular benefits in elderly subjects. Such results have important clinical applications since the increase of VO2peak is related with reduced risk of mortality (Lee et al., 2011), and exercise interventions which are effective in improving this parameter, with lower expenditure of time, may facilitate their adoption.

Our findings also have implications for professionals designing exercise programs to improve health and fitness in the elderly population. In this regard, a twice weekly combined strength and endurance training would be more practical and efficient for older adults to optimize neuromuscular and cardiovascular training adaptations. The present data expand the knowledge of previous findings related to the efficiency of different weekly frequencies of training in an elderly population, since it shows that concurrent training performed twice a week is a sufficient stimulus to elicit maximal strength, muscle mass and VO2peak gains.

In conclusion, in trained older men, concurrent training performed twice a week promotes similar increases in maximal dynamic strength and muscle thickness when compared to the same program performed three times per week. In addition, both weekly frequencies result in similar increases in cardiovascular variables. However, it should be mentioned that only three training sessions per week induced increases in maximal power on cycle ergometer in the previously trained elderly men. Finally, the low frequency of combined strength and endurance training for older adults may facilitate the adherence to exercise while also optimizing physical fitness at comparable benefits obtained in higher weekly frequencies.

**Conflict of interest**

The authors declare no duality of interest for the present manuscript.

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