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Review Article

Strength and Endurance Training Prescription in Healthy and Frail Elderly

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ABSTRACT: Aging is associated with declines in the neuromuscular and cardiovascular systems, resulting in an impaired capacity to perform daily activities. Frailty is an age-associated biological syndrome characterized by decreases in the biological functional reserve and resistance to stressors due to changes in several physiological systems, which puts older individuals at special risk of disability. To counteract the neuromuscular and cardiovascular declines associated with aging, as well as to prevent and treat the frailty syndrome, the strength and endurance training seems to be an effective strategy to improve muscle hypertrophy, strength and power output, as well as endurance performance. The first purpose of this review was discuss the neuromuscular adaptations to strength training, as well as the cardiovascular adaptations to endurance training in healthy and frail elderly subjects. In addition, the second purpose of this study was investigate the concurrent training adaptations in the elderly. Based on the results found, the combination of strength and endurance training (i.e., concurrent training) performed at moderate volume and moderate to high intensity in elderly populations is the most effective way to improve both neuromuscular and cardiorespiratory functions. Moreover, exercise interventions that include muscle power training should be prescribed to frail elderly in order to improve the overall physical status of this population and prevent disability.

Key words: resistance training, frailty, power output, functional outcomes, aerobic capacity

Biological aging is associated with declines in the neuromuscular and cardiovascular systems, resulting in an impaired capacity to perform daily activities [1-5]. In addition, age-related muscle power decrease is also an important predictor of functional limitations in healthy elderly [6-12], as well as in institutionalized frail oldest old [13].

Strength and endurance training promote specific neuromuscular and cardiovascular adaptations. The adaptations induced by strength training include muscle hypertrophy [14], increase in the motor unit recruitment capacity and motor unit firing rate [15-18]. These neuromuscular adaptations result in improved muscle strength and power development [19,20]. In contrast, endurance training induces central and peripheral adaptations that improve the cardiovascular function and the capacity of skeletal muscles to generate energy via oxidative metabolism. Thus, a combination of strength and endurance training (i.e., concurrent training) in elderly populations is the most effective way to enhance both neuromuscular and cardiorespiratory functions and consequently to preserve the functional capacity [21-23]. However, some studies have been shown that the concurrent training induces lower strength gains when

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compared with strength training alone, and this effect has been called "interference effect" [24-26]. Therefore, the simultaneous development of both neuromuscular and cardiovascular adaptations is not so simple.

Although several studies have investigated the concurrent training on young populations [24-31], a limited number have explored the concurrent training adaptations in elderly [32-37]. Thus, in order to optimize the concurrent training prescription in elderly, it seems relevant to identify the most effective combination of training variables (i.e., intensity, volume, weekly frequency, exercise-order) to promote both neuromuscular and cardiovascular adaptations in the elderly.

Frailty is an age-associated biological syndrome characterized by decreases in the biological functional reserve and resistance to stressors due to changes in several physiological systems, which puts individuals at special risk for poor outcomes (disability, loss of independency and hospitalization) from minor stressors [38-41]. However, poor health, disability and dependency do not have to be inevitable consequences of aging. The benefits of physical exercise in improving the functional capacity of frail older adults have been the focus of considerable recent research [42-46]. Thus, the positive effects of strength training on muscle strength, as well as the benefits of endurance training on the cardiovascular system of frail elderly should be also discussed.

Therefore, the first purpose of this descriptive review was discuss the neuromuscular adaptations to strength training, as well as the cardiovascular adaptations to endurance training in healthy and frail elderly subjects. The second purpose of this study was investigate the concurrent strength and endurance training adaptations in the healthy elderly.

Strength training in healthy elderly

Strength training is an effective way to enhance muscle strength, power output, maximal neuromuscular activity, and muscle mass in elderly populations. The magnitude of these adaptations seems to be similar than those observed in untrained young subjects. The clinical relevance of the neuromuscular adaptations induced by strength training is its impact on the daily living activities, especially when the strength training is performed with high-speed of movement in the concentric phase [8-13,47-49].

Effects on muscle strength and power output: the influence of intensity, volume and velocity of movement

Studies investigating the muscle strength and power improvements induced by strength training in elderly have shown that training protocols composed by single or multiple-sets per exercise (constant or progressive volume), intensity ranging from 40 to 85% of one maximum repetition (1RM), and weekly frequency ranging from one to three sessions per week result in average increases of 20 - 70% (or even more) in training periods ranging from 6 to 24 weeks [3,8-11,19,47-51].

Regarding the influence of training intensity on the strength gains, some studies have shown that there are no differences in the strength enhancements in elderly between moderate (50-65% of 1RM) and high (70-80%) training intensities [50,51]. However, recent meta-analyses have shown that moderate to high training intensities (65-80% of 1RM) resulted in higher maximal strength effect-sizes [20,52].

On the other hand, muscle power output is optimized when stimulated by training at low intensities (40-50% of 1RM) and higher velocity of movement than training at high intensity and low velocity [11,53]. These results are easily explained because the optimal power output is produced at lower intensities (40 - 60% of 1RM) rather than higher intensities of training [6,7]. The benefits of muscle power improvements in the functional capacity of elderly will be discussed later in the present review.

The strength training volume also has an important association with the magnitude of neuromuscular adaptations. Regarding the number of sets per exercise, some studies have investigated whether greater training volumes (i.e., 3 sets per exercise) result in greater magnitude of strength increases than lower volume (i.e., 1 set per exercise). In study of Cannon and Marino [54], one and three sets per exercise induced similar strength gains after 10 weeks of strength training in elderly women. In contrast, Galvão and Taaffe [55] have shown greater strength gains in elderly men and women who trained during 20 weeks with three sets per exercise, when compared with those who performed one set per exercise. In a recent study, Radaelli et al. [56] have shown similar strength gains between one and three sets per exercise after 6 and 12 weeks of strength training. Nevertheless, the same authors showed greater strength gains in the group who trained with greater volume for longer periods (>20 weeks) (unpublished observations). Thus, it seems that during short periods of training (i.e., 6-12 weeks), one set per exercise may be sufficient to optimize the strength gains in elderly, whereas greater volumes should be performed to optimize the strength gains in longer periods of training.

The effects of different strength training weekly frequencies have also been compared in elderly subjects. Farinatti et al. [57] compared one vs. two vs. three strength training sessions per week in women over 60 years old. All the three groups performed 1 set of 10RM in different exercises. These authors showed that the higher frequency (2 and 3 sessions) improved the strength and functional capacity in a greater extent than the lower frequency (1 session) of training. In other study, Holviala et al. [58] showed that one strength training session per week is not sufficient to result in further strength increases in previously strength trained elderly. These authors showed that only the group which trained twice per week achieved further strength increases.

Based on the above mentioned studies, it may be suggested that moderate to high (65 - 80% of 1RM) training intensities induce greater strength gains, whereas lower intensities and high velocity of movement are necessary to optimize the power output in elderly. It should be mentioned that the muscle power training should be performed at low to moderate intensities (i.e., 40-60% of 1RM), in order to optimize the power development during the exercise [6,7]. In addition, it seems that during the first weeks of training (i.e., 6 weeks), one set per exercise may improve the strength at same extent than three sets per exercise, while in longer periods of time, three sets per exercise may result in greater strength gains. Finally, two to three training sessions per week appear induce greater overall enhancements in the strength when compared with one session per week.

The functional benefits of the inclusion of power training in elderly

The capacity to perform daily activities, such as walking, climbing stars, and gardening among others, is critical to maintain the independent functioning in elderly individuals [12,13]. Recently, age-related declines in muscle power-output have emerged as an important predictor of functional limitations in older adults [4,6,7,8-13]. The inclusion of explosive contractions in strength training results in overall neuromuscular adaptations in the elderly, such as increases in the maximal power, rate of force development and rapid muscle activation [19,47,49,53,59]. Moreover, some studies have shown that strength training using explosive concentric contractions induces greater enhancements in functional outcomes compared with traditional strength training (i.e., slow contractions only) [9,11,59]. In the study by Correa et al. [59], power training including exercises with stretch-shortening cycle enhanced functional outcomes more than traditional strength training in elderly women. Similarly, Bottaro et al. [11] showed greater increases in functional performance in a strength training performed with high-velocity muscle contractions when compared with a traditional strength training intervention. Thus, muscle power seems to be an important predictor of functional performance in elderly adults, which reinforce the idea that exercises using high-velocity concentric contractions should be included during a strength training periodization.

Effects on muscle hypertrophy

Sarcopenia is a consequence of biological aging that is exacerbated by decreased physical activity, which causes a decline in the overall function. To counteract this process, several studies have shown marked increases in the muscle mass in elderly populations [19,22,47,48,56,59-61]. Although the capacity of hypertrophy in these subjects may be lower than young subjects [62], studies have shown increases between 5 and 15% of muscle cross-sectional area (CSA) and muscle thickness of the quadriceps femoris in elderly, in training periods ranging from 6 to 30 weeks [19,56,63-68].

In study of Häkkinen et al. [67], 12 weeks of strength training twice per week, with intensity ranging from 30 to 80% of 1RM, including explosive muscle actions resulted in 14% of muscle CSA increases in older men and women. In other study, Kraemer et al. [62] compared the strength training adaptations between young and elderly men after 10 weeks of training. These authors showed that a strength training periodization performed 3 times a week, including sets of 2-5 RM, 8-10 RM and 12-15RM resulted in 6% of muscle hypertrophy in elderly, although this CSA increase was lower when compared with young men (14%). In contrast, Cannon et al. [68] tested the effects of 10 weeks of strength training performed at intensity almost constant during the training periodization (50% of 1RM in the first 2 weeks and 75% of 1RM from week 3 to 10). These authors showed 12% of quadriceps muscle CSA increase, which was not statistically different than the muscle CSA increases observed in young subjects (13%).

As above-mentioned, the high-velocity strength training may result in superior improvements on the muscle power output and functional capacity than traditional strength training. Therefore, an interesting question that arises is whether this type of training could result in similar muscle hypertrophy using similar intensity or even when using lower intensity of training. In order to investigate this question, Nogueira et al. [61] have shown that knee extensors muscle thickness increased only after explosive strength training (11%) when compared with traditional strength training using the same intensity (i.e., 40-60% of 1RM) (5.5%, non-significant). In another study, Correa et al. [59] compared a group that performed traditional strength training (i.e., 8-10RM) performed at slow velocity, with a group that changed the leg press exercise by the step exercise (i.e, stretch-shortening cycle type) performed at explosive way using only the body mass as workload. These authors showed similar muscle hypertrophy after 6 weeks of both types of training in elderly women. The muscle CSA improvements using light to moderate load and explosive contractions during the strength training could be

Table 1. Neuromuscular adaptations to strength training in health elderly

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.

explained due to the type II fibers selective recruitment when high-velocity muscle actions are performed [61]. Thus, from a practical point of view, along with the functional outcomes improvements, the explosive strength training also promotes muscle hypertrophy at least in the same magnitude than the traditional strength training.

More recently, it has been shown that even a short-term strength training (i.e., 6 weeks) promotes marked quadriceps muscle hypertrophy in elderly women [65]. In addition, during short-term strength training period (i.e., 6-12 weeks), it seems that the same magnitude of increases in the elbow flexors and quadriceps muscle thickness are observed using 1 or 3 sets per exercise in elderly women [56]. Therefore, we can conclude that different strength training programs may result in muscle hypertrophy in elderly women and men. This benefit may be achieved using low to moderate volume and intensity of training, performing slow or high-velocity of muscle actions and during short periods of time. These results are very important taking into consideration the muscle mass decreases which accompanies the human aging. Table 1 presents the results and training intervention details of studies which investigated the effects of strength training in healthy elderly.

Special issue: positive effects of strength and muscle power training on frail elderly

Although several studies on strength training in the elderly have shown that this type of exercise intervention can promotes marked neuromuscular adaptations in healthy elderly, a lower number of studies have investigated the effects of strength training in the physically frail subjects. Fiatarone et al. [69] studied the adaptations induced by strength training in 100 physically frail, oldest old men and women. The subjects underwent strength training that consisted of 3 sets of 8 repetitions at 80% of 1RM, 3 times per week for 10 weeks. The results revealed that the strength training group improved their leg muscle strength outcomes (220%). In a study by Serra-Rexach et al. [70], 20 oldest-old subjects (90-97 years of age) underwent strength training 3 times a week for 8 weeks, with 2-3 sets of 8-10 repetitions at 30% of 1RM in the initial phase of training, progressing to 70% of 1RM. The results demonstrated increases in the leg press strength (10.6 kg). In addition, Hennessey et al. [71] observed significant 1RM increases after 24 weeks of strength training in frail elderly individuals (71.3 ± 4.5 years of age). In this study, the participants performed 3 sets of 8 repetitions at 20% of 1RM, progressing gradually to 95% of 1RM. In another study, Lustosa et al. [72], observed significant improvements in the power at 180 $^{\circ s-1}$ in pre-frail elderly subjects (72 ±4 years of age) after 12 weeks of strength training that was performed 3 times per week.

The effectiveness of different training intensities (% of 1RM) has also been investigated in frail elderly. Sullivan et al. [73], have shown greater strength increases in the training groups that underwent progressively the intensity of the resistance training (starting at 20% and progressing to 80% of 1RM) compared with the low-intensity training groups that underwent resistance training (at 20% of 1RM during the entire 12-week training period).

Therefore, strength training interventions performed 3 times a week, with 3 sets of 8 to 12 repetitions and an intensity starting at 20-30% and progressing to 80% of 1RM, may be tolerated by frail subjects, resulting in marked muscle strength gains. No injuries or side effects were mentioned in the studies above-mentioned, which investigated the strength training in frail subjects [46,69-75].

Recently, it has been reported that 12 weeks of multicomponent exercise training including explosive resistance training improved muscle power output, strength, muscle cross-sectional area and fat infiltration, as well as functional outcomes and dual task performance in frail institutionalized nonagenarians [45]. Thus, exercise interventions that also include muscle power training should be prescribed to frail oldest old because such interventions improve the overall physical status of this population and prevent disability.

Endurance training in healthy elderly

Endurance training (ET) induces central and peripheral adaptations that enhance VO_{2max} and the ability of skeletal muscles to generate energy via oxidative metabolism. These adaptations include enhanced mitochondrial biogenesis, myoglobin content, capillary density, substrate stores, and oxidative enzyme activities [75,76], as well as enhanced maximal cardiac output [77]. In addition, endurance training may induce small increases in the muscle strength, especially when performed on cycle ergometer [22,32].

Effects on cardiorespiratory fitness

Endurance training is an effective way to counteract the cardiorespiratory decline observed during aging [78-81]. In study of Hepple et al. [78], elderly individuals were assessed before and after 9 and 18 weeks of endurance training on cycle ergometer, performed 3 times per week during 30 minutes. After 9 weeks, there was a significant improvement on peak oxygen uptake (VO_{2peak}) (16%), as well as on the maximal workload on cycle ergometer (W_{max}) (11%). After 18 weeks, there was an additional increase on the VO_{2peak} compared with 9 weeks (6%).

Along with the VO_{2peak} increases, this study showed significant increases on the capillary density (35%) after the first 9 weeks of training.

Several others studies investigating the effects of endurance training in elderly have shown increases ranging from 8 to 20% in the VO_{2peak}, and W_{max}, after periods ranging from 12 to 24 weeks, weekly frequency of 3 to 5 times per week, duration of exercise ranging from 30 to 60 minutes and intensity ranging from 50 to 85% of the maximal heart rate [23,78-81]. In addition, adaptations such as a reduction in cardiovascular responses to the same submaximal load (i.e., economy of movement) have also been observed [22,81]. Moreover, another important adaptation to endurance training is the reduction in the neuromuscular activity during cycling at the same workload after the endurance training, which has been called neuromuscular economy [23,82].

As mentioned, the capacity to increase the cardiorespiratory fitness is preserved during the aging, and elderly individuals must be strongly encouraged to engage in endurance training programs. Such results have important clinical applications since the increase of VO_{2peak} is related with reduced risk of mortality [83]. Table 2 summarizes the methods applied and the results observed in the studies that investigated the endurance training adaptations in the elderly.

Special issue II: Endurance training on frail elderly

Frail elderly may not be able to perform endurance training due to their limited neuromuscular capacity, and the fact that cardiorespiratory capacity is positively associated with muscle power and strength levels in elderly subjects [2,82,84]. Thus, endurance interventions in frail elderly should be included within a multi-component exercise programs [42-46,85,86].

Table 2. Cardiorespiratory adaptations to endurance training in healthy elderly

Autor	Period and weekly frequency	Training volume and intensity	Main results
Hepple et al. [78]	18 wk; 3 times/wk	30 min, intensity not described	↑ VO_{2peak}(16%); ↑ W_{max}(15%).
Levy et al. [79]	24 wk; 4-5 times/wk	45 min, 50 – 85% of HR_{max}	↑ VO_{2peak}(21%).
Meijer et al. [80]	12 wk; 2 times/wk	30 min, 50% of HR_{max}	↑ VO_{2peak}(8%); ↑ W_{max} (8%); ↓ HR at 70 and 100W.
Okazaqui et al. [81]	18 wk; 3 times/wk	60 min, 50 – 85% of VO_{2peak}	↑ VO_{2peak}(20%); ↑ VT_1 (9%).
Izquierdo et al. [22]	16 wk; 2 times/wk	30-40 min, 70 – 90% of HR_{max}	↑ W_{max}(16%); ↓ HR at 120W.
Karavirta et al. [36]	21 wk, 2 times per wk	30 -60 min cycling below LVT_1, between VT_1 and VT_2, and above VT_2.	↑ VO_{2peak}(10%).
Sillanpaä et al. [35]	21 wk, 2 times per wk	30 -60 min cycling below LVT_1, between VT_1 and VT_2, and above VT_2.	↑ VO_{2peak}(10%).
Holviala et al. [34]	21 wk, 2 times per wk	30 -60 min cycling below LVT_1, between VT_1 and VT_2, and above VT_2.	↑ VO_{2peak}(11%); ↑ W_{max}(15%) ↑ exercise time (11%)
Cadore et al. [23]	12 wk; 3 times/wk	20-30 min, 80 – 100 of HR in the VT_2	↑ VO_{2peak}(20%); ↑ W_{max} (19%); ↑ neuromuscular economy.

↑, increase; ↓, decrease; wk, weeks; min, minutes; times/wk, number of training sessions per week; VO_{2peak}, peak of oxigen uptake; W_{max}, maximal power at cycle ergometer; VT_1, first ventilatory threshold; VT_2, second ventilatory threshold; HR, hearte rate; HR_{max}, maximal HR.

Endurance training for frail individuals should include walking with changes in pace and direction [42-44,46,87], treadmill walking [43,86], step-ups, stair climbing, and stationary cycling [43,46]. The endurance exercises may start with a duration of 5-10 minutes in the first weeks of training, progressing to 15-30 minutes for the remaining program [44,85,86]. Ehsani et al. [88] assessed the effect of endurance training on frail elderly, starting with 20 minutes and progressing to 60 minutes of walking at intensity of 70-75% of the maximal heart rate. This endurance exercise intervention resulted in approximately 12% of increase in the maximal oxygen uptake (VO_{2max}) [88]. However, it should be mentioned that in this study, the endurance training was performed after 2 previous phases of training, composed by 1 month of physical therapy and 1 month of strength training. Thus, it may be necessary to strengthen the neuromuscular system before initiating endurance training to achieve these cardiovascular adaptations.

Due to the mentioned relevance of the aerobic capacity as a component of physical fitness, endurance training should be part of the exercise intervention for frail elderly patients. Although no studies have compared the effectiveness of various endurance training programs (i.e., different intensities and volumes), this type of exercise should follow the basic principles of training, with the intensity and duration progressively increased based on the capacity of each participant.

Concurrent strength and endurance training in healthy elderly

Studies investigating the effects of concurrent strength and endurance training have shown that this combination may induce lower magnitude of strength and power gains when compared with strength training alone, and this effect has been called “the interference effect” [14,28,29,32,89]. However, several other studies have observed similar strength gains when comparing strength and concurrent training (CT) [21,90-93]. Although several studies have focused on young populations [24-27,30,31], a limited number have explored the effects of concurrent training on strength and endurance performance in older age [21-23,32-35,66,94].

The advantage of prescribing strength training (ST) simultaneously with endurance training (ET) is the improvements of both neuromuscular and cardiovascular functions, even when the muscle strength increases at lower magnitude when compared with strength training alone.

Effects on muscle strength and power

In elderly, most of the studies reported that concurrent training induced similar strength adaptations using two sessions per week of each modality (i.e., strength and endurance) when compared with ST alone [34,35,94]. However, three times a week of concurrent training can result in an interference effect in this population [32,37]. In addition, the time-course of strength development during a concurrent training periodization may be influenced by the weekly training frequency [32]. Furthermore, it has been shown that intra-session exercise sequence may also influence the magnitude of strength adaptations in the elderly, and performing strength training prior to endurance exercise may optimize the neuromuscular adaptations in this population [33,95].

Izquierdo and Colleagues [22] investigated the effects of 16 weeks of strength, endurance and concurrent training among elderly men. In this study, the ST and ET groups performed specific training twice a week, and the CT group performed strength exercises on one day and cycle ergometer on the other day. These authors demonstrated that after 16 weeks of training, similar lower-body strength gains were observed in the ST and CT groups, which suggests that a minimum weekly frequency of concurrent training may promote an optimal stimulus to strength gains in previously untrained elderly subjects [22].

Using similar training volumes for ST and CT groups, Karavirta et al. [94] observed similar strength gains (i.e., from 14 to 22%) and similar improvements in muscle power output (~16%) in the groups after 21 weeks of training twice a week in 40-67-year-old men. Using similar training volume, intensity, and weekly frequency, other studies have shown similar strength and power gains induced by strength and concurrent training in older men [34,35,96,97], and older women [98].

Increasing the weekly training frequency from two to three sessions per week may induce the interference effect in elderly men who perform concurrent training. Investigating elderly men, Cadore et al. [32] reported that 12 weeks of training performed three times a week led to greater dynamic and isometric strength in the leg extensor muscles in the group that performed only strength training (67%) when compared with a combined strength and cardiovascular group (41%), whereas similar upper-body strength gains were evidenced in the strength and concurrent training groups (30-33%). Moreover, increases in the maximal isometric force were observed only in the strength training group (14%). These results suggested that the interference effect of endurance training on strength adaptations occurs only in the specific muscle groups that perform both strength and endurance exercises (i.e., lower-limbs). Although an interference effect was observed in the CT group, this group exhibited a similar magnitude of strength gains in relation to the results of the above-mentioned studies (i.e., approximately 20-30%) [34,35,96-98], and the same strength adaptations occurred in a shorter period of time (12 vs. 21 weeks). These different time courses in strength development could be explained by the different weekly frequencies of training performed. Cadore et al.’s [32] subjects performed three training sessions per week, in contrast with subjects in other previous studies, who performed two training sessions per week (i.e., ~30% lower volume) [34,35,96,97]. In contrast, Ferrari et al. [66] have shown that a weekly frequency of three times a week did not promote greater strength gains in well-trained healthy elderly subjects when compared with twice per week (22 vs. 20% respectively). These authors suggested that in previously concurrent trained elderly subjects, twice per week may be an optimal weekly frequency to enhance muscle strength.

Another factor related to the CT session that may influence the magnitude of strength adaptations in the elderly is the intra-session exercise sequence. Greater maximal dynamic strength gains (35 vs. 21%) and greater force per unit of muscle mass (27 vs. 15%) were observed in a concurrent group that performed strength training prior to endurance exercise, when compared with the inverse order [33,95], after 12 weeks of concurrent training using a similar training periodization that previously resulted in an interference effect [32]. It may be suggested that fewer strength gains obtained after the endurance-strength exercise (ES) sequence could be related to the ES group's lower workloads in the training periodization [95].

Effects on muscle hypertrophy

Although several studies have investigated the effects of strength training on the muscle mass in older subjects, a lower number of studies have explored the effects of concurrent training on muscle hypertrophy in this population. In the study by Izquierdo et al. [22], no differences were observed between the ST group (twice a week) and CT group (1 session per week of strength and 1 session per week of cycle endurance training) in the magnitude of hypertrophy after 16 weeks of training (~11%). A unique finding of this study was that only one day of ST combined with another day of ET performed using cycle ergometer resulted in enhanced muscle mass in the elderly after 16 weeks.

In another study, Karavirta et al. [94], have shown increase in the cross-sectional area (AST) of type II muscle fibers of the vastus lateralis only in the strength training group (~16%), whereas no changes were observed in the concurrent training group. However, this difference did not result in a difference in strength gains. In other studies utilizing a training weekly frequency ranging from two to three times, intensities from 40 to 80% of 1RM (progressive load during training periodization) and multiple sets produced marked increases in muscle mass (9-16%), with no differences between the strength and concurrent training interventions [34-35,94,96-98]. Moreover, although the intra-session exercise sequence influenced strength adaptations, it is important to note that the sequence of strength and endurance exercise had no influence on muscle mass gains [95]. As observed in the muscle strength, Ferrari et al. [66] have shown similar muscle hypertrophy comparing a weekly frequency of three times a week with twice per week (approximately 5 % in the four quadriceps muscles) in previously concurrent trained elderly subjects.

Effects on cardiorespiratory fitness

Along with the decrease in the maximal cardiac output [99], several authors have demonstrated that the cardiorespiratory fitness declines are also associated with strength and power decreases related with aging [3,19,82]. In line of this, some studies have shown that the combination of strength and endurance training is a better strategy to improve the cardiovascular performance of the elderly when compared with strength training alone. In addition, the performance of strength training simultaneously with endurance training does not impair the cardiovascular adaptations produced by endurance training alone [21-23,34-36].

Studies that have investigated cardiovascular adaptations to CT have demonstrated increases ranging from 10 to 18% in the maximum oxygen uptake and maximal cycle ergometer workload in elderly people who underwent training periods ranging from 12 to 21 weeks, and a weekly frequency ranging from two to three training sessions [21,22,32,34,97,100]. Similar to the results observed in the strength performance and hypertrophy above mentioned, Izquierdo et al. [22] observed similar aerobic power gains in elderly men who underwent 1 session per week of strength training and 1 session per week of cycle endurance training in the CT group (28%) and those who underwent ET twice per week (23%) after 16 weeks of training.

Interestingly, in the study by Cadore et al. [33], similar enhancements were observed in the peak oxygen uptake, maximal workload at cycle ergometer, and the workload at the second ventilatory threshold among groups that performed strength training prior to an endurance exercise sequence and the opposite exercise order. However, greater improvement was found in the workload at the first ventilatory threshold in the group that strength trained prior to endurance exercise in each session. It is possible that this difference was observed as a consequence of the greater increases in the muscle strength achieved by performing strength training prior to endurance training, as strength gains have been associated with maximal and submaximal endurance gains [3,23]. Recently, Ferrari et al. [66] have shown similar VO_{2peak} increases after 10 weeks of concurrent training performed two or three times a week in well trained subjects. However, greater maximal workload gains were observed in the group who trained three times per week, suggesting that in trained elderly, it may be necessary greater weekly frequency to promote additional cardiorespiratory gains.

Conclusions

Strength training is an effective intervention to improve muscle strength, power output, and muscle mass in healthy and frail elderly populations. Endurance training induces improvements on VO_{2max} and submaximal endurance capacity in these populations. Therefore, a combination of strength and endurance training (i.e., concurrent training) in elderly populations is the most effective way to improve both neuromuscular and cardiorespiratory functions. Based on recent evidence, concurrent training performed at moderate weekly frequency (i.e., 2 times per week) may promote marked gains on muscle hypertrophy, strength and power gains in elderly subjects. The strength training should be performed at moderate- to high-intensity (i.e., 60-80% of 1RM), and moderate volume (i.e., 2 to 3 sets per exercise). Also, endurance training should be performed at moderate- to high-intensity (i.e., 60-85% of VO_{2max}), and moderate volume (i.e., 25 to 40 minutes). For concurrent training protocols in which both strength and endurance training are performed on the same day, the strength and endurance gains may be optimized with strength training prior to endurance intra-session exercise sequence. Moreover, twice per week may be an optimal weekly frequency to promote additional muscle mass and strength gains, as well as cardiorespiratory fitness in previously concurrent trained elderly. Regarding improving the functional capacity of the elderly, the concurrent strength and endurance training prescription should include high-velocity strength training, designed to improve muscle power output, as muscle power has been associated with the functional capacity in elderly.

In addition to the positive effects of concurrent training on the functional capacity of healthy elderly individuals, another issue that must be further investigated is the potential benefits of combined strength and endurance training on the functional capacity of physically frail individuals, because such intervention improve the overall physical status of this population, maintain the independency and prevent disability and other adverse outcomes. Based on the current knowledge, it seems that exercise interventions that include endurance, strength, and muscle power training should be prescribed to frail elderly in order to improve the functional capacity.

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