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Repetitions to failure versus not to failure during concurrent training in healthy elderly men: A randomized clinical trial

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ABSTRACT

This randomized clinical trial compared the neuromuscular adaptations induced by concurrent training (CT) performed with repetitions to concentric failure and not to failure in elderly men. Fifty-two individuals (66.2 ± 5.2 years) completed the pre- and post-measurements and were divided into three groups: repetitions to failure (RFG, n = 17); repetitions not to failure (NFG, n = 20); and repetitions not to failure with total volume equalized to RFG (ENFG, n = 15). Participants were assessed in isometric knee extension peak torque (PT_{iso}), maximal strength (1RM) in the leg press (LP) and knee extension (KE) exercises, quadriceps femoris muscle thickness (QF MT), specific tension, rate of torque development (RTD) at 50, 100 and 250 ms, countermovement jump (CMJ) and squat jump (SJ) performance, as well as maximal neuromuscular activity (EMG_{max}) of the *vastus lateralis* (VL) and *rectus femoris* (RF) muscles. CT was performed over 12 weeks, twice weekly. Along with each specific strength training program, each group also underwent an endurance training in the same session. After training, all groups improved similarly and significantly in LP and KE 1RM, PT_{iso}, CMJ and SJ performance, RTD variables, specific tension, and VL EMG_{max}, ($P < 0.05$–0.001). QF MT improved only in RFG and ENFG ($P < 0.01$). These results suggest that repetitions until concentric failure does not provide further neuromuscular performance gains and muscle hypertrophy, and that even a low number of repetitions relative to the maximal possible (i.e., 50%) optimizes neuromuscular performance in elderly men. Moreover, training volume appears to be more important for muscle hypertrophy than training using maximal repetitions.

1. Introduction

Biological aging is associated with declines in maximal strength, muscle mass and quality, muscle explosiveness (i.e., rate of force or torque development), muscle power output, as well as cardiorespiratory capacity, which results in an impaired capacity to perform activities of daily living (Fleg and Lakatta, 1998; Izquierdo et al., 1999a, 1999b; Aagaard et al., 2010). In view of this, concurrent strength and endurance training seems to be the best strategy to counteract this process in healthy elderly individuals, because it induces both neuromuscular and cardiovascular gains (Wood et al., 2001; Izquierdo et al., 2004; Cadore et al., 2010, 2011; Ferrari et al., 2013).

Performing repetitions until concentric failure has been widely used during strength training (ST) regimens (Kraemer et al., 1999; Cadore et al., 2010; Izquierdo-Gabarren et al., 2010; Sampson and Groeller, 2016). In healthy elderly people, ST using repetitions to failure seems to result in marked neuromuscular gains (Izquierdo et al., 2004; Kraemer et al., 1999; Pinto et al., 2014; Cadore et al., 2012). However, several studies have shown that ST performed with repetitions until concentric failure does not induce additional muscle strength and power output gains when compared to repetitions not to failure (i.e., submaximal repetitions per set) in young populations (Folland et al., 2002; Izquierdo et al., 2006; Izquierdo-Gabarren et al., 2010; Sampson and Groeller, 2016; Martorelli et al., 2017), whereas a fewer number of studies observed greater strength gains following repetitions to failure (Rooney et al., 1994; Drinkwater et al., 2005). In addition, it seems that ST with repetitions to failure (i.e., maximal repetitions per set) does not induce further muscle size gains in young subjects (Sampson and

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Groeller, 2016; Martorelli et al., 2017; Nóbrega et al., 2018), although its effects are less investigated. Notwithstanding, to the best of the authors' knowledge, no previous study has compared the performance of ST with repetitions to failure or not to failure (i.e., submaximal per set) in elderly populations. Moreover, it is still unclear what is the minimal number of repetitions needed, in relation to the maximal possible, to optimize the neuromuscular adaptations in the elderly; this issue needs to be further investigated.

Although ST performed with repetitions until concentric failure induces improvements in several neuromuscular parameters (Cadore et al., 2010; Pinto et al., 2014; Cadore et al., 2013), it also results in a longer time under tension, which induces greater increases in the blood pressure, heart rate, and rate-pressure product (Nery et al., 2010; Lovell et al., 2011; Gjovaag et al., 2016), which could increase the cardiovascular risk in elderly. In addition, ST with repetitions to failure induces greater metabolic impact (Gorostiaga et al., 2012), which may result in greater time of recovery necessary between exercise sessions. Thus, it seems relevant to compare the effects of performing repetitions to failure and not to failure in the neuromuscular adaptations to training in elderly, giving special attention to the influence of total volume on these adaptations (i.e., compensating or not compensating the number of repetitions with additional sets). Moreover, this information would be especially useful in the context of concurrent training, since it is an effective strategy to improve overall neuromuscular and cardiovascular functions in elderly (Cadore and Izquierdo, 2013). Therefore, the aim of the present study was to compare the neuromuscular adaptations induced by three types of concurrent training interventions in healthy elderly men: one with the ST performed with repetitions until concentric failure; another with ST performed with 50% of the repetitions to concentric failure; and a third, with ST performed with 50% of the repetitions to concentric failure, but equalizing the total volume by adding more sets. Our hypothesis was that all training groups would induce similar neuromuscular performance gains, although we expected that the groups with greater ST volume would have greater muscle size gains.

2. Materials and methods

2.1. Experimental design

To investigate the effects of concurrent training composed by ST workout performed with repetitions until concentric failure in elderly individuals, three training groups performed 12 weeks of different interventions. Because we also aimed to isolate the effects of ST volume (i.e., sets × repetitions), two training groups performed submaximal repetitions (i.e., 50% of the possible maximal repetitions), but one of them compensated for the lower number of repetitions per set by performing double the number of sets than the group which performed repetitions to failure, which resulted in equal volume. To test the stability and reliability of the performance variables, a subsample of the participants were assessed twice before the start of training (weeks –4 and 0). Pre- and post-intervention testing was performed by the same investigator, who was blinded to the training group to which the participants belonged. Exception of blindness was in the 1 RM variables, in which assessors were not completely blinded regarding individuals' groups, but blinded in relation to the pre-training values. The ambient conditions were kept constant throughout all tests (temperature: 22–24 °C) and interventions. This randomized clinical trial (RCT) was conducted according to the Declaration of Helsinki and approved by the local Institutional Ethics Committee (register number 39550914.3.0000.5347).

2.2. Participants

The complete screening, recruitment, and allocation of individuals are presented in the "*Results*" section (Fig. 1). Fifty-two healthy community-dwelling elderly men (mean ± SD: 66.2 ± 5.2 years) who had not engaged in any regular and systematic training program in the previous 3 months participated in this study after completing an ethical consent form. The participants volunteered for the present investigation following announcements in widely read local newspapers, social media, and announcements at a local University. The participants were carefully informed about the design of the study, and special information was given regarding the possible risks and discomfort related to the procedures. Subsequently, the participants were randomly assigned and placed into three groups: concurrent training with the ST performed using repetitions until concentric failure (RFG, n = 17); concurrent training with the ST performed using repetitions not to failure (NFG, n = 20); and, concurrent training with the ST performed using repetitions not to failure, but with equalized total ST volume, comparing to RFG (ENFG, n = 15). Concealment was guaranteed by a researcher who was blinded with respect to participants. Twelve individuals (age: 68.0 ± 5.2 years; body mass: 83.0 ± 9.7 kg; height: 170 ± 7 cm; body mass index: 28.7 ± 4.2 kg·m^{-2}) were evaluated twice before the start of training to provide control period data (weeks –4 and 0).

Medical evaluations were performed using clinical anamnesis and an effort electrocardiograph (ECG) test to ensure each subject's suitability for the testing procedure. The exclusion criteria included any history of neuromuscular, metabolic, hormonal and cardiovascular diseases (except controlled stage 1 hypertension). In addition, exclusion criteria also included smoking or having stopped smoking less than one year prior to the participation in the study. The participants were not taking any medications that could influence hormonal or neuromuscular metabolism. The participants were advised to maintain their normal dietary intake throughout the study. The physical characteristics of the participants were assessed as described elsewhere (Cadore et al., 2013) and in the Supplementary file, as well as are shown in Table 1.

2.3. Maximal dynamic strength

Maximal strength was assessed using the one-repetition maximum test (1 RM) on the bilateral leg press (LP) and bilateral knee extension (KE) exercises (KonnenGym, Beijing, China). More details on familiarization, warm-up and procedures are described elsewhere (Cadore et al., 2013), and in the Supplementary file. Each subject's maximal load was determined with no more than five attempts with a five-minute recovery between attempts. Performance time for each phase (concentric and eccentric) was 2 sec, controlled by an electronic metronome (Quartz, CA, USA).

2.4. Isometric peak torque and rate of torque development

Maximal isometric peak torque (PT_{iso}) was obtained using an isokinetic dynamometer (Cybex Norm, New York, USA). The dynamometer was connected to a 2000 Hz A/D converter (Miotec, Porto Alegre, Brazil), which made it possible to quantify the torque exerted when each subject executed the knee extension at the determined angle. Participants were seated with their hips and thighs firmly strapped to the seat of the dynamometer, with the hip angle at 85° and the lateral femoral condyle of the right leg was aligned with the axis of rotation of the dynamometer. More details on warm-up as well as on assessment and analysis procedures are described elsewhere (Cadore et al., 2013), and in the Supplementary file. Three 5-second knee extensions were performed with 120° in the knee extension (180° represented the full extension), with 2 min of rest interval between each attempt. All participants were instructed and encouraged to exert maximum strength "as hard and as fast as possible" after the starting command. Signal processing included filtering at a cut-off frequency of 10 Hz. Maximal peak torque was defined as the highest value of the torque (N·m) recorded during the unilateral knee extension. The isometric torque-time analysis on the absolute scale included the maximal torque