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Functional and physiological adaptations following concurrent training using sets with and without concentric failure in elderly men: A randomized clinical trial

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ABSTRACT

This study compared the functional and physiological 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 that in the RFG (ENFG, $n = 15$). The participants' sit-to-stand ability, timed-up-and-go (TUG), muscle power output in squat jump (SJ) and countermovement jump (CMJ), peak oxygen uptake (VO_{2peak}), blood lipids and glucose, as well as blood pressure levels were assessed. A subsample of our participants ($n = 22$) also underwent assessment of body composition by dual X-ray absorptiometry (DXA). CT was performed twice weekly for over 12 weeks. In addition to the specific strength training (ST) programme, each group also underwent endurance training (ET) in the same session (i.e., ST immediately followed by ET). After training, all groups improved similarly and significantly in their sit-to-stand ability ($P < 0.01$), muscle power output relative to body mass in SJ and CMJ ($P < 0.001$), VO_{2peak} ($P < 0.01$) and HDL cholesterol levels ($P < 0.001$). There were reductions in the total, leg and trunk percent fat mass as well as increases in the total, leg and trunk percent lean mass (P values ranging from $P < 0.05$ to $P < 0.01$). Independent of performing repetitions until concentric failure and greater ST volumes, all CT groups exhibited improved sit-to-stand ability, muscle power output, VO_{2peak} and HDL cholesterol levels. In addition, our preliminary data suggest that there are no differences in the effects of the assessed CT approaches on body composition outcomes. We therefore highlight the need for additional well-powered studies to assess whether repetitions to failure could underlie distinct effects on body composition.

1. Introduction

Intrinsic capacity is the composite of all of the physical and mental capacities that an individual can draw on. The World Health Organization (WHO)'s public health framework for healthy ageing identifies three phases of the intrinsic capacity trajectories across the ageing: high and stable capacity, declining capacity and significant loss of capacity (WHO, 2015). The progressive declines in neuromuscular and cardiovascular functions associated to biological ageing dramatically impact functional abilities, such as gait ability, stair climbing, and sit-to-stand ability, especially after the sixth decade of life (Reid and Fielding, 2012; Casas-Herrero et al., 2013). Although muscle strength and aerobic capacity have a strong influence on functional performance, muscle power output seems to be more associated with functional capacity, and power output decreases during ageing impairs its performance (Izquierdo et al., 1999a, 1999b; Reid and Fielding, 2012).

An impaired functional capacity contributes to the reduced time

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spent with daily physical activity (PA) (Izquierdo and Cadore, 2014). Along with more declines in functional capacity, the reduction in PA levels also induces an increase in the incidence of cardiometabolic diseases, such as hypertension, dyslipidaemia and diabetes mellitus type 2 (Fiuza-Luces et al., 2013). Therefore, strategies to improve neuromuscular and cardiovascular function can couple benefits to slow down the declines in the capacity to perform activities of daily living, at least partially preserve PA levels, and ultimately reduce the risk of developing cardiometabolic diseases (Fiuza-Luces et al., 2013). Prospective observational evidence has shown that adults meeting both recommended strength and aerobic exercise guidelines had a 25% lower risk of developing metabolic syndrome (HR, 0.75; 95% CI, 0.63–0.89) (Bakker et al., 2017). Therefore, the combination of strength and aerobic training (i.e., concurrent training) has been regarded as the best modality to attenuate the neuromuscular, functional and cardiometabolic consequences of ageing (Wood et al., 2001; Izquierdo et al., 2004; Cadore et al., 2011, 2012; Ferrari et al., 2016; Wilhelm et al., 2014).

Strength training (ST) using repetitions until concentric failure [i.e., repetitions maximal (RM) per set] has often been used in healthy elderly individuals and has been shown to induce marked neuromuscular gains (Cadore et al., 2013; Cadore and Izquierdo, 2013). However, it remains unclear whether repetitions to failure provide further functional adaptations in elderly individuals because, to the best of the authors' knowledge, no previous study has investigated this issue in elderly populations. In young adults, most of the studies in this area have shown that ST with repetitions to failure do not induce further neuromuscular adaptations when compared to repetitions not to failure (Folland et al., 2002; Izquierdo et al., 2006; Izquierdo-Gabarren et al., 2010; Martorelli et al., 2017), whereas fewer studies have shown some advantage of repetitions to failure (Rooney et al., 1994; Drinkwater et al., 2005). Moreover, considering a repetitions-not-to-failure approach, the minimal number of repetitions needed to induce optimal gains in functional capacity in the elderly is still unclear.

It has been shown that ST sets performed until failure induces greater muscular fatigue and metabolic impact at the cellular level (Gorostiaga et al., 2012). Thus, one could suggest that inducing more muscular fatigue could also contribute at a greater extent to endurance capacity gains when combined with endurance training (i.e., concurrent training) than would induce ST with less muscular fatigue (i.e., submaximal repetitions per set). Moreover, although it has been shown that ST is a positive component in the management of blood pressure (Cornelissen et al., 2011), blood lipids (Kelley and Kelley, 2009), and glucose levels (Umpierre et al., 2011), it is not clear if an ST programme using maximal or submaximal repetitions in large muscle groups would provide different effects on cardiometabolic risk factors. It could be hypothesized that due to the higher metabolic impact of ST with repetitions to failure approach, further improvements in some metabolic parameters may be induced (i.e., blood lipids, percent fat mass, glucose). However, to the best of the authors' knowledge, this hypothesis has not been investigated.

ST performed with repetitions to failure can be associated with a lot of discomfort, and thus, it is also important to investigate the physiological adaptations to ST performed not to failure, as this approach could result in a greater exercise adherence over the long-term. Therefore, the first purpose of this study was to assess the effects of performing repetitions to failure and not to failure during concurrent training on functional capacity and maximal power output in healthy elderly individuals. The second purpose was to compare the effects of repetitions to failure and not to failure during concurrent training on physiological parameters such as cardiorespiratory capacity and cardiometabolic risk outcomes in these individuals. Our main hypothesis was that repetitions to failure would not provide further enhancements in the functional capacity and muscle power output when compared with repetitions not to failure.

2. Methods

2.1. Experimental design

To compare the effects of concurrent training consisting of ST workouts using repetitions to concentric failure or not to failure on functional capacity, power output, endurance capacity and cardiometabolic risk factors (i.e., blood pressure, blood lipids, glucose, body composition) in elderly men, three training groups performed 12 weeks of different concurrent training interventions. This randomized clinical trial is part of a large project, and data on neuromuscular outcomes (i.e., maximal strength, rate of torque development, maximal neuromuscular activity and muscle thickness) have been published elsewhere (da Silva et al., 2018). The primary outcomes in this study were functional test performance and maximal power output, and the secondary outcomes were VO_{2peak}, blood lipids and glucose, blood pressure, and body composition. 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 $kg{\cdot}m^{-2}$) were evaluated twice before the start of training to test stability and reliability of data (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 subjects belonged. The exception to blinding was in the functional outcomes, in which assessors were not completely blinded regarding the individuals' groups but were blinded regarding the pre-training values. 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 procedure for the screening, recruitment, and allocation of individuals has been published elsewhere (da Silva et al., 2018) and is presented in the Fig. 1. Fifty-two healthy community-dwelling elderly men (mean ± SD: 66.2 ± 5.2 years) who had not engaged in any regular systematic training programme in the previous 3 months participated in and completed this study after completing an ethical consent form. The participants volunteered for the present investigation following announcements in widely read local newspapers, on social media, and 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 allocated into one of three available groups: concurrent training with ST performed using repetitions until concentric failure (RFG); concurrent training with ST performed using repetitions not to failure (NFG); or concurrent training with ST performed using repetitions not to failure but with total ST volume equalized to that in the RFG (ENFG). The randomization sequence was computer generated by a researcher blinded to the participants.

Medical evaluations were performed using clinical anamnesis and an effort electrocardiograph (ECG) test to ensure the participants' suitability for the testing procedure. The exclusion criteria included any history of neuromuscular, metabolic, hormonal and cardiovascular diseases (except for controlled stage 1 hypertension). In addition, the exclusion criteria included smoking or having stopped smoking less than one year prior to participation in the study. The participants were advised to maintain their normal dietary intake throughout the study. Physical characteristics of the participants are presented in Table 1, and the methods of assessment are presented in the Supplementary file. Medications taken by the participants are shown in the Supplementary file.

2.3. Functional tests

Functional capacity was assessed using timed-up-and-go (TUG) and