

Effects of 6 Weeks of Low-Volume Combined Training on Muscle Power, Muscular Strength, and Aerobic Power in Active Young Adults

Los Efectos de 6 Semanas de Entrenamiento Combinado de Bajo Volumen Sobre la Potencia Muscular, la Fuerza Muscular y la Potencia Aeróbica en Adultos Jóvenes Activos

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Abstract. The effects of combined training (CT) on sports performance are well established likewise, the potential of low-volume exercise on physical fitness. However, the efficacy of low-volume CT on measures of physical fitness requires more research. Thus, the aim of this study was to analyse the effects of low-volume CT performed during 6 weeks on muscle power, muscular strength, and maximal aerobic power (W_{max}). Eighteen healthy, active young adults men (mean \pm SD, 20.06 \pm 1.66 years; 22.23 \pm 2.76 kg/m²) performed either a low-volume CT (EG, n=9), or maintained a normal life (CG, n=9). The CT was composed by a resistance training (RT), 2 sets of 3 exercises with 80 to 85% 1RM, followed by a high intensity-interval training (HIIT), 5 sets of 60'' with 95% W_{max} . The measures of jump height, 1 maximal-repetition (1RM) in bench press and back squat, W_{max} , and internal load were obtained before and after training for analysis. Furthermore, an ANOVA test of repeated measures and t-test paired samples were used with a $p \leq 0.05$. The main results demonstrated that low-volume CT increased the jump height ($p \leq 0.05$), 1RM on bench press and back squat ($p < 0.001$ and $p < 0.001$, respectively) and W_{max} ($p \leq 0.01$). In addition, the internal load had not significant differences between weeks ($p > 0.05$). For active young adults, the low-volume CT is effective and a time-efficient strategy to improve, jump height, 1RM in bench press and back squat, and W_{max} without increasing the internal load.

Keywords: Exercise, Concurrent training, Physical fitness, Performance, Cardiorespiratory fitness, Untrained.

Resumen. Los efectos del entrenamiento combinado (EC) en el rendimiento deportivo están bien establecidos, así como el potencial del ejercicio de bajo volumen en la aptitud física. Sin embargo, la eficacia de la EC de bajo volumen en las medidas de aptitud física requiere más investigación. Por lo tanto, el objetivo de este estudio fue analizar los efectos de la EC de bajo volumen realizado durante 6 semanas sobre la potencia muscular, la fuerza muscular y la potencia aeróbica máxima (W_{max}). Dieciocho hombres adultos jóvenes sanos y activos (promedio \pm DE, 20,06 \pm 1,66 años; 22,23 \pm 2,76 kg/m²) realizaron una EC de bajo volumen (GE, n=9) o mantuvieron una vida normal (GC, n=9). El EC fue compuesto por un entrenamiento de fuerza (EF), 2 series de 3 ejercicios con 80 a 85% 1RM) seguido de un entrenamiento de intervalos de alta intensidad (HIIT), 5 series de 60'' con 95% W_{max}). Las medidas de la altura de salto, 1 repetición máxima (1RM) en press de banca y sentadilla trasera, W_{max} y carga interna se obtuvieron antes y después del entrenamiento para el análisis. Además, se utilizó una prueba ANOVA de medidas repetidas y muestras pareadas con un $p \leq 0,05$. Los principales resultados demostraron que lo EC de bajo volumen aumentó la altura de salto ($p \leq 0,05$), 1RM en press de banca y sentadilla trasera ($p < 0,001$ y $p < 0,001$, respectivamente) y W_{max} ($p \leq 0,01$), a pesar de que la carga interna no tuvo diferencias significativas entre semanas ($p > 0,05$). Para los adultos jóvenes activos, la TC de bajo volumen es efectiva y una estrategia tiempo eficiente para mejorar, la altura del salto, lo 1RM en press de banca y sentadilla, y la W_{max} , sin aumentar la carga interna.

Palabras clave: Ejercicio, Entrenamiento concurrente, Aptitud física, Rendimiento, Aptitud cardiorrespiratoria, No entrenado.

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Introduction

In sports, some modalities benefit from the simultaneous development of aerobic (i.e, cardiorespiratory fitness [CRF]) and anaerobic capacities (i.e, strength, and power) to increase sports performance (Doma et al., 2019; García-Pallars & Izquierdo, 2011; Wong et al., 2010). Combined training (CT) is defined as performing resistance training (RT) plus aerobic training (AT) in the same session. Furthermore, the CT plays an important role in the development of many components of physical fitness (PF) associated to sports performance and is used by several coaches (Balabinis et al., 2003; Eddens et al., 2018; Murlasits et al., 2017; Schumann et al., 2021). The CT appears to increase muscular strength (Balabinis et al., 2003; Eddens et al., 2018; Murlasits et al., 2017; Schumann et al., 2021), muscle hypertrophy (Balabinis et al., 2003; Schumann et al., 2021), CRF (Balabinis et al., 2003; Murlasits et al., 2017; Wong et al., 2010), anaerobic capacity (Balabinis et al., 2003), and muscle power (Balabinis et al., 2003; Guillen

Pereira et al., 2020; Schumann et al., 2021; Wong et al., 2010). Despite these advantages for PF, the training sessions may be very long (i.e., > 60 min) which might be considered a limitation for this strategy (Ashton et al., 2017; Galvim et al., 2019). However, CT allows a more reduction in total time spent in exercise, than performing RT and AT in single sessions (Markov et al., 2022), without affecting the chronic adaptations to both types of exercise (Murlasits et al., 2017; Schumann et al., 2021). Nevertheless, a wary prescription of CT is needed, due to the potential interference effects in RT outcomes, like strength and power (Eddens et al., 2018; Hickson, 1980; Schumann et al., 2021).

Low-volume high-intensity interval training (HIIT) is a type of AT, in which the weekly volume is less than ACSM guidelines, ≥ 500 metabolic equivalent - MET/min/week.(Garber et al., 2011) These protocols seem to be able to increase the CRF, however, they are not enough to change body composition (Sultana et al., 2019), nevertheless, are effective strategies for improving

performance in athletes (Nugent et al., 2017). For RT, the low-volume is defined by single sets, low repetitions, and high load (American College of Sports Medicine, 2009), with a low weekly frequency (American College of Sports Medicine, 2009), which seem to improve muscular strength in untrained individuals (American College of Sports Medicine, 2009; Fyfe et al., 2021; Garber et al., 2011), and in trained individuals, when the training frequency is twice or three times a week (Fyfe et al., 2021). As well as the low-volume RT can increase muscle power and function (Fyfe et al., 2021), besides that RT programs with single sets per exercise were sufficient to increase the upper-limb strength, muscle size, and functional capacity in middle aged and older adults (Marques et al., 2023)

So, the benefits for sports performance of CT are already known, as well as the efficacy of low-volume exercise to improve some components of PF. However, there is a lack of literature that aimed to analyse all these variables in a single exercise protocol to reduce the total time spent in exercise and get the benefits of both training methodologies. Therefore, the aim of this study was to analyse the effects of 6 weeks of low-volume CT on muscle power, muscular strength, and maximal aerobic power (W_{max}) in healthy active young adult men.

Materials and methods

Participants

Eighteen healthy active young males, students of sports degree were recruited to participate in this study. The subjects were not involved in any training routine, either RT, AT, or both, for at least 6 months, but were involved in practical activities associated with the undergraduate study plan such as football, handball, and fitness activities up to 4 hours per week. During the experimental period, participants were not involved in any more recreational activities or any type of physical exercise. All subjects underwent pre-exercise screening to ensure they had established neither cardiovascular, metabolic, or respiratory disease nor signs or symptoms of disease, musculoskeletal injuries, health problems nor required medication. The use of any type of supplementation or ergogenic substance was not permitted and, subjects were instructed not to change their diet or lifestyle over the experimental period. The physical characteristics of each group are shown in Table 1. All subjects signed a written informed consent and voluntarily agreed to participate in this study, and all procedures were approved by the Polytechnic Institute of Beja ethics committee (CEIPBeja).

Measures

Anthropometry

Measurements were done using a stadiometer with an accuracy of 1 cm (Seca mod. 213), and the subjects were measured shoeless. Body weight was measured from a calibrated scale with an accuracy of 0.1kg (SC-330, Tanita Corp, Tokyo, Japan).

Table 1.

Baseline characteristics of each group

| Variables (units) | EG (n = 9) | | CG (n = 9) | | p |
|--------------------------|---------------|-------|---------------|-------|------|
| | Mean | SD | Mean | SD | |
| Age (years) | 20.56 | 1.67 | 19.56 | 1.59 | 0.21 |
| Body weight (kg) | 69.51 | 10.59 | 70.36 | 10.67 | 0.87 |
| Height (m) | 1.76 | 0.07 | 1.79 | 0.08 | 0.39 |
| BMI (kg/m ²) | 22.46 | 2.88 | 21.99 | 2.78 | 0.73 |
| Squat jump height (cm) | 29.28 | 3.81 | 30.82 | 4.35 | 0.44 |
| 1RM back squat (kg) | 63.11 | 12.23 | 65.89 | 12.66 | 0.64 |
| 1RM bench press (kg) | 56.11 | 11.35 | 52.33 | 15.99 | 0.57 |
| W_{max} (watts) | 200 | 30 | 211.67 | 35.53 | .463 |

Note: Data are presented in mean \pm SD. CG = Control group; EG = Experimental group; BMI = Body mass index; 1RM = 1 maximal repetition; W_{max} = maximal aerobic power. Statistically significant values ($p \leq 0.05$) are presented with *.

Squat Jump Height

It was measured employing the squat jump test, based on kinematic equations that use the flight time measured using Optojump (Microgate Co., Bolzano, Italy), following the protocol (Glatthorn et al., 2011). Before starting the test, a warm-up of 5 minutes was performed with low-intensity body weight exercises and a pre-test submaximal jump. The subjects started from the upright standing position with their hands on their hips, they were then instructed to flex their knees and hold a predetermined knee position (approximately 90), and the experimenter then counted out for 3 seconds. On the count of 3, the subject was instructed to jump as high as possible without performing any countermovement before the execution of the jump. Was recommended that at take off the subjects leave the floor with the knees and ankles fully extended. Three jumps were made with two minutes rest between each try and only the highest value was analysed (Glatthorn et al., 2011).

1 Repetition-Maximal

The 1 maxima repetition (1RM) was analysed in the horizontal bench press and back squat, all of them were made with an olympic bar with 20kg and in a free hack. A linear velocity transducer (T-Force System Version 3.60, Ergotech, Murcia, Spain) was used to predict 1RM in each exercise (Martínez-Cava et al., 2020). This equipment automatically calculates the kinematics of each repetition performed and provides %1RM, the mean propulsive velocity, and both are used for the calculation of the 1RM by software (González-Badillo & Serna, 2020). Only loads above 60% of 1RM were used for pre-evaluation, to increase the reliability of the measurement and in the post, evaluation was used the same load established in the post-evaluation (Martínez-Cava et al., 2019, 2020). The general warm-up consisted of performing 5 minutes of exercises with low-intensity (i.e., jumping jacks and split jacks), 2 sets of 20 repetitions each, followed by gentle stretching and joint mobilization, the specific warm-up was 2 sets of 5 repetitions with 20 and 30 kg for bench press and back squat, respectively. Subsequently, 1 set of 3 repetitions was performed, where the load was progressively increased with small and individual increments (i.e., 2.5 to 10kg) until the relative load was over 60% of 1RM. The intervals periods between sets were 3 to 5 minutes. Unlike the eccentric phase, which was

performed at a controlled mean bar velocity (~ 0.50 to 0.70 m s^{-1}) for standardization and security reasons, participants were verbally and strongly encouraged to perform the concentric action at the maximal intended velocity. Only the concentric phase and the repetitions that match with a full range of motion and technique were analysed, like touch on the chest on bench press and 60° of knee flexion in the sagittal plan on back squat. On bench press, subjects were not allowed to bounce the bar off their chests so as not to boost the bar velocity (Pallarés et al., 2014). The two exercises technique were described in (Martínez-Cava et al., 2019; Ribeiro et al., 2020), nevertheless, the back squat was performed only until 55° and 65° of tibiofemoral flexion in the sagittal plane. The range of motion was guaranteed by a bench placed behind the subject, and they were encouraged to only touch and not sit down.

Maximal Aerobic Power

W_{\max} , was measured by a maximal graded exercise test on a cycle ergometer (GXT CE) with mechanical calibration (Ergonomic 828E, Monark, Sweden), under the supervision of the investigator and following the protocol of Storer and collaborators (Storer et al., 1990). The warm-up consisted of 2 minutes with a 60 Watts (W) of load with a pedal rate of 60 repetitions per minute (RPM), after that the intensity was increased by 15 W every minute. The test was interrupted when it was no longer possible to maintain 60 RPM or until the subjects reach their limit of tolerance. The protocol was adapted in the warm-up, to not cause too long tests and avoid prediction errors (Beltz et al., 2016). Subjects were verbally encouraged before and during the test administrators to provide a true maximal effort. W_{\max} was recorded in the final stage only when this stage was fully completed.

Volume Load

The volume load (VL) was calculated in all sessions using the following formula: (number of series \times number of repetitions \times external load in kg). To calculate the total weekly VL, the total volume of all exercises in that same week was added. Only repetitions performed with a full range of motion and with a proper technique were included in the analysis. The values are expressed in kilograms (kg) (Scott et al., 2016).

Internal Load

The Category ratio-10 scale (CR-10 RPE) of rating perceived exertion (RPE) was used to measure the exercise intensity (Day et al., 2004). The internal load was calculated by multiplying the RPE by the total session time in minutes (RPE \times total session time in min) (Scott et al., 2016). For the calculation of the weekly internal load, each value of internal load per session was added per week, the data are presented in arbitrary units (a.u). To avoid measurement errors, before starting an explanation of the tool consisted of and familiarization with the scale were performed. The subjects were asked to evaluate the total effort of the session. The values were recorded after 15 minutes from the end of session (Scott et al., 2016).

Procedures

Using a non-randomized, between groups design (experimental group [EG] and control group [CG], respectively), 18 young adults were evaluated. To investigate the potential effects of low-volume-CT on power, strength, and aerobic capacity, the measures of squat jump height, 1RM on bench press and back squat, and W_{\max} on graded incremental test on cycle ergometer were performed before and after a 6 weeks intervention period. All subjects performed familiarization trials before the testing days and one familiarization training session prior to the intervention period. The first physical contact with subjects was a familiarization trial followed by pre-test measures and later was done a familiarization training session. The following weeks were the intervention period, ending in the post-test measures at the last week. All measures were performed in the laboratory with the supervision of the researcher, as well as the same conditions between them were guaranteed. All subjects were asked to avoid vigorous and intense physical activities at least 48 hours before tests. The order of evaluation was established, equal to all individuals and assessments: jump height, 1RM in the squat, 1RM in the bench press, and at the end the evaluation of the W_{\max} in the cycle ergometer. The subjects were allocated into two groups, the CG ($n = 9$) that did not perform any experimental procedure and followed their daily routine, and the EG ($n = 9$) who underwent an RT followed by a HIIT on the cycle ergometer, explained below. No dropouts were reported during the experimental period. The experimental design, subjects, procedures and low-volume CT protocol were replicated from this study (Martins & Loureiro, 2023).

Combined Training Protocol

The CT was performed twice a week with 48 hours of interval between each training session for 6 weeks in a row, with a physical exercise technician always supervising the training sessions. The general warm-up was the same as used for the 1RM tests. The specific warm-up was 1 sub-maximal set of 6 repetitions with 60% of 1RM to enhance the force production and power during the work sets (Ribeiro et al., 2020). The CT protocol consisted of a session of RT before HIIT on a cycle ergometer (i.e., Monark 828E), this training order was employed due to less chance of concurrent effect for lower-body dynamic strength, whereas maximal aerobic capacity is not affected by CT order (Eddens et al., 2018). For the RT, 2 sets of three multi-joint exercises, squat with a hexagonal bar, flat bench press with bar, and 30° incline bench pull with bar, always in this order, were performed. The rest interval of 2 minutes between sets and exercises, were strictly controlled. The subjects were instructed to perform the repetition movement velocity (i.e., Tempo) in 3 to 4 seconds for the eccentric phase and a maximal intended velocity in the concentric phase. All exercises and sets were performed at an intensity between 80 to 85% of 1RM (6 to 8 RM) during all intervention. The subjects were instructed to perform all sets to concentric failure or close to it. The load progression was

made according to the 2-by-2 rule (2 to 5% for upper limbs and 5 to 10% for lower limbs) (Baechle & Earle, 2011). The loads used, and repetitions performed by all participants were recorded for the calculation of the VL. After 3 minutes of passive rest, the HIIT started on a cycle ergometer. The warm-up consisted of 2 minutes with 15 to 45 W at 60 RPM. Then, 5 sets of 60 seconds at 80 to 90 RPM with 95% W_{max} with 90 seconds of active pause at 50-60 RPM with a self-suggested load up to 60W were performed. The work:rest ratio was 1:1.5 and at the end, the calm down was 2 to 3 minutes at 50 to 60 RPM with a self-suggested load. No injuries or dropouts were reported, and the training adherence was 100%.

Statistical Analysis

The normality and homogeneity (Shapiro–Wilk e Levene test, respectively) were conducted in all data before analyses. All data were presented in mean \pm SD and adopted 95% confidence intervals. For the comparison between groups, an independent samples T-test was used. An ANOVA of repeated measures was used to analyse the effects time, groups, and the interaction time-group of jump height, 1RM bench press, 1RM squat, W_{max} , VL, and internal load. The paired-samples T-test was used to compare the means between groups in the pre and post measures. The alpha criterion for significance was set at $p \leq 0.05$. All data processing was performed in the Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, Version 27.0, IBM Corp., Armonk, NY, USA).

Results

There were not significant differences in baseline measures between groups ($p > 0.05$) (Table 1).

Squat jump height

A significant group \times time interaction was observed for jump height ($Z_{1,16} = 5.703$, $p = 0.030$), only in EG (pre: 29.28 \pm 3.81 cm vs. post: 32.02 \pm 3.09 cm, $p \leq 0.05$) (figure 1).

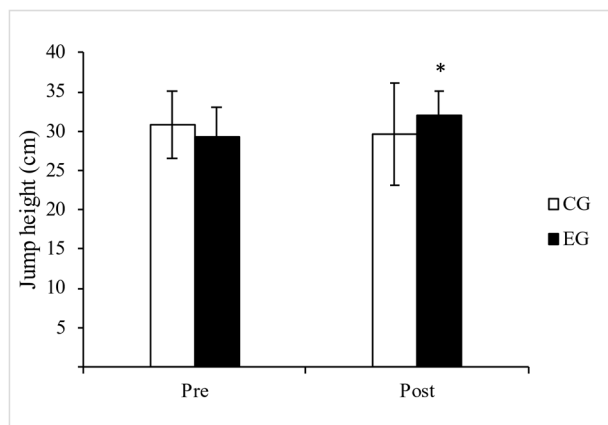


Figure 1. Jump height between the pre and post measurement of both groups. * represent $p \leq 0.05$ vs. pre of the same group. CG = Control group; EG = Experimental group;

1RM bench press

A significant group \times time interaction was observed for 1RM in the bench press ($Z_{1,16} = 14.214$, $p = 0.002$), only

in EG (pre: 56.11 \pm 11.35 kg vs. post: 67.67 \pm 13.36 kg, $p < 0.001$) (figure 2).

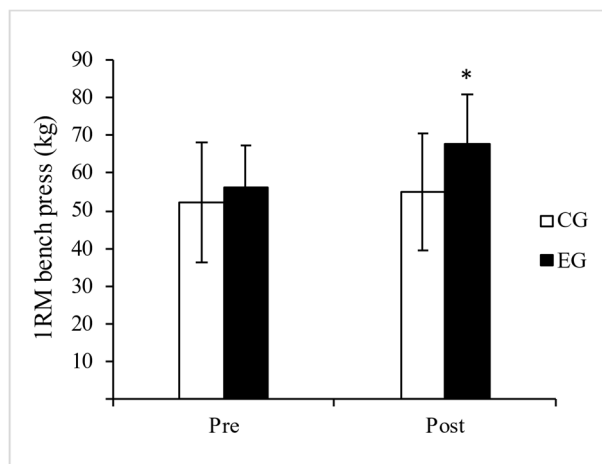


Figure 2. 1RM in bench press between the pre and post measurements of both groups. * represents $p < 0.001$ vs. pre of the same group. CG = Control group; EG = Experimental group; 1RM = 1 maximal repetition.

1RM back squat

A significant group \times time interaction was observed for 1RM in the back squat ($Z_{1,16} = 22.149$, $p < 0.001$), only in EG (pre: 63.11 \pm 12.25 kg vs. post: 74.00 \pm 12.02 kg, $p < 0.001$) (figure 3).

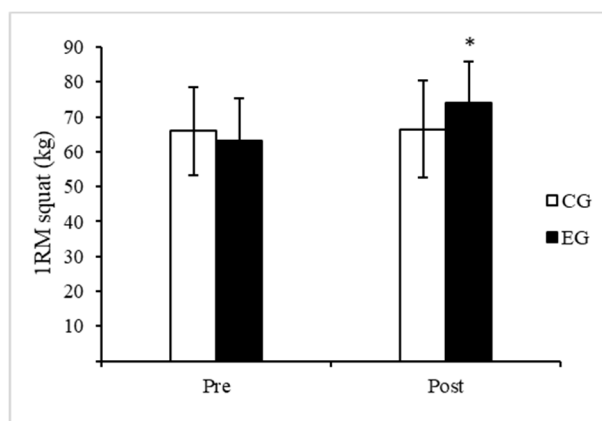


Figure 3. 1RM in squat between the pre and post measurements of both groups. * represents $p < 0.001$ vs. pre of the same group. CG = Control group; EG = Experimental group; 1RM = 1 maximal repetition.

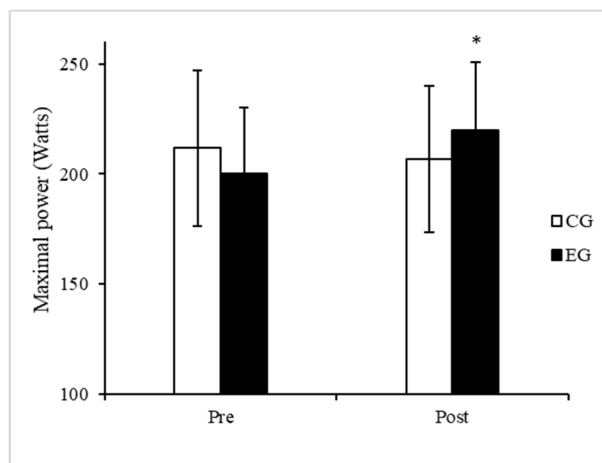


Figure 4. W_{max} between the pre and post measurement of both groups. * represents $p \leq 0.01$ vs. pre of the same group. CG = Control group; EG = Experimental group; W_{max} = Maximal aerobic power.

W_{\max}

A significant group \times time interaction was observed for W_{\max} ($Z_{1,16} = 14.286$, $p = 0.002$), only in EG (pre: 200.00 ± 30.00 W vs. post: 220.00 ± 30.92 W, $p \leq 0.01$) (figure 4).

VL

There was a significant main effect of time in VL ($Z_{4, 40} = 14.446$, $p < 0.001$) (figure 5).

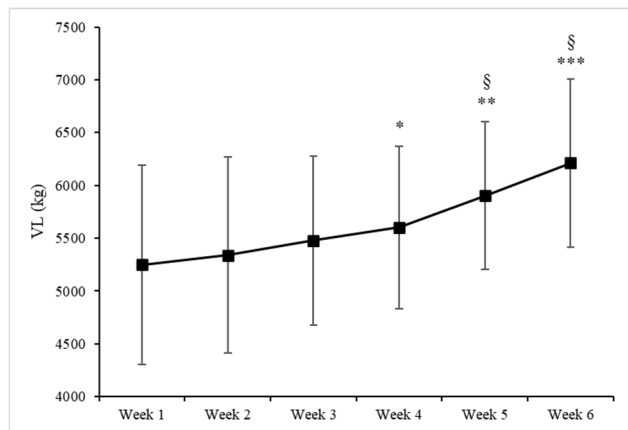


Figure 5. Weekly VL during weeks 1, 2, 3, 4, 5 and 6 in the EG. * represents $p \leq 0.05$, ** represents $p \leq 0.01$, and *** represents $p < 0.001$ both vs. Week 1. § represents $p \leq 0.05$ vs. previous week. VL = Volume load, EG = Experimental group.

Internal Load

No changes in internal load occurred between weeks during the intervention period ($Z_{5,40} = 1.764$, $p = 0.143$).

Discussion

The purpose of this study was to examine the effects of 6 weeks of low-volume CT on muscle power, muscular strength, and W_{\max} in healthy active young adult men. The main results showed that all components of PF analysed, muscle power, muscular strength, and maximal aerobic capacity improved significantly through low-volume CT. The VL had a significant and progressive tendency to increase between weeks, and without differences in internal load.

The neuromuscular component that seems to be most attenuated by CT is the muscle power or rapid/explosive force, due to a phenomenon called "interference effect", which affects chronic adaptations in power (Chtara et al., 2008; Fyfe et al., 2016; Häkkinen et al., 2003; Schumann et al., 2021). Despite the greater interference effect, due to the possible limitation of neural activation speed (Häkkinen et al., 2003), CT can significantly increase muscle power (Chtara et al., 2008; Fyfe et al., 2016; Häkkinen et al., 2003; Schumann et al., 2021). In addition, the CT is also feasible to increase in long-term the explosive strength when the CT is planned through a sport's movement based system (Guillen Pereira et al., 2020). Moreover, a work did not report any harmful effect at the jump height between the group that performed the CT and the group that only did RT (Balabinis et al., 2003). A study that assessed the jump height by the squat jump test also found a significant improvement of 6.6% after 12 weeks of CT (Shamim et al.,

2018), nevertheless, the AT and RT were performed on alternate days, which is a strategy used to minimize the effect of interference between aerobic and neuromuscular adaptations (Eddens et al., 2018; Schumann et al., 2021). This study also found significant improvements of 9.4% in jump height. These results suggest that for young active adults low-volume CT may be enough to increase vertical jumping capacity, which is related to the anaerobic potency of lower limbs (Gross & Lüthy, 2020). Also, owing to the design of low-volume CT, which was created to minimize the interference effect from CT, by allocating the RT first in the session, low-volume of AT with high relative intensity and short bouts performed in the cycle ergometer (Methenitis, 2018). This chronic adaptation can be explained by improving the voluntary neural activation speed, related to the motor neuron recruitment speed and maximal motor unit discharge rate (del Vecchio et al., 2019).

For muscular strength, it is already well documented in the literature, that CT increases maximal strength in the upper limbs and the lower limbs (Eddens et al., 2018; Murlasits et al., 2017; Schumann et al., 2021), which agrees with the results obtained in this study either for 1RM in the bench press or for 1RM in the squat. In this study, the RT was done before the HIIT which is the order that had better results to increase 1RM (Eddens et al., 2018; Murlasits et al., 2017). A study of Winett et al. found that even low-volume CT was able to improve strength in various exercises in untrained subjects (Winett et al., 2003). Another article methodologically similar to our study, which prescribed a higher daily volume for both, RT and AT, found improvements in the half squat strength (Tsitkanou et al., 2017). Similarly, another work from our laboratory, showed a significant improvement in muscle strength measured by handgrip strength after the same low-volume CT protocol (Martins & Loureiro, 2023). The low weekly volume presented in this study appears to be effective to create neuromuscular adaptations and this result is supported by other articles that the prescription of a single set with a low weekly volume of RT were sufficient to increase maximal strength (Fyfe et al., 2021; Kirk et al., 2007). This improvement can be explained by adaptations, especially neural, in relation to structural adaptations, due to the duration of the intervention period (Pearcey et al., 2021). Some of these adaptations could be related to the increase of motor unit firing frequency and synchronization, motor unit recruitment thresholds, motoneurons excitability, and an improvement in antagonist muscle coactivation (Pearcey et al., 2021). Another interesting detail was the magnitude of the improvements in the present study (20.59% for bench press and 17.25% for squat) compared to other CT studies, which were on average, an increase of 16.55% in bench press (Fyfe et al., 2016; Silva et al., 2012), and 23.6% in squat (Hickson, 1980; Hunter et al., 1987; McCarthy et al., 1995). A possible interpretation of these results is that for upper limbs strength the low-volume CT can be as effective to increase strength as higher volume CT, however, for the lower limbs the higher volume seems to

be more effective for active untrained individuals. Despite this, more studies are required to be able to successfully compare the effects of CT of different volumes on muscle strength.

The CRF seems to be the component of PF with more positive responses to CT, due to a small or inexistent interference effect between training bouts, independently of exercise order (Eddens et al., 2018; Murlasits et al., 2017). The W_{max} is the maximal capacity to generate energy through aerobic metabolism (Hill & Lupton, 1923). Improvements in W_{max} are supported by this information and the positive association between CRF and W_{max} (Beltrame et al., 2020). This could be explained, particularly for untrained subjects, due to an increase in myofibrillar and mitochondrial protein synthesis, as well as mitochondrial biogenesis after CT (Fyfe et al., 2014). An investigation led by Lee, found that after 9 weeks of CT with a higher weekly volume, moderately active young adults increased 7.1% of W_{max} (Lee et al., 2020). The increase of 8.8% in W_{max} was also obtained by Fyfe et al. as a result of 8 weeks of CT with a higher volume training protocol performed by active subjects (Fyfe et al., 2016). Another study with a duration of 12 weeks of CT conducted by Shamim et al. in young active adults, resulted in a 14% increment in W_{max} (Shamim et al., 2018). The results reported in these studies are relevant when compared with our outcomes owing to, we had an increase of 10% in W_{max} with a lower weekly training volume than the above-mentioned studies. This suggests that a smaller training volume may be as effective as a higher volume to increase aerobic capacity in young active adults nonetheless, more studies are needed to confirm that.

When measuring CRF through VO_{2max} , there is more evidence pointing in the same way. The work of Winnett et al. who performed a low-volume CT protocol achieved significant improvements in VO_{2max} in untrained subjects during 12 weeks of training (Winnett et al., 2003). When addressing CT with a higher volume there is a wide literature that indicated significant improvements in VO_{2max} (Bell et al., 2000; Chtara et al., 2005; Hickson, 1980; Kraemer et al., 1995).

For the measures of training load, the progressive increase in weekly VL between weeks was supported due to the application of the principle of progressive overload applied in the training sessions, which was the 2-by-2 rule (Baechle & Earle, 2011). These increments in VL could be associated with strength improvements in untrained men (Peterson et al., 2011), this relationship may explain the increase in muscle strength, due to the increase in VL in the 6th week. Despite this increase in VL, the internal load did not increase and still presented a decreasing trend, which was not seen in the study of Fyfe et al., which had some oscillations in the internal load (Fyfe et al., 2016). That could be explained by the study design due to, the change in the intensity zone of RM among the weeks of intervention, as well as its multifactorial response (McLaren et al., 2018). The internal load is a psychophysiological indicator where the effort of the entire training session is measured

in a relative mode (Scott et al., 2016), and a higher internal training load can increase vulnerability for diseases or injuries (Jones et al., 2016). With these results is expected a decrease in injury or disease risk caused by the exercise, due to there was less effort and less perceived physiological stress along the low-volume CT protocol.

This investigation has some limitations which should be considered before drawing conclusions. The group sample is small, which can affect the statistical power, and was also composed of a group of sport's degree students, who have already practiced physical activity before and during the experimental period. Nevertheless, there was a CG that had the same features as the EG, however did not perform the CT protocol. The training protocol duration was only 6 weeks, even though it was already possible to see significant differences in PF. Food, alcohol intake, or tobacco intake were not controlled, although subjects were asked to keep their usual routines. The training sessions were not given on the same days or at the same time, nevertheless the researchers always tried to ensure an interval of 48h between workouts to provide a good recovery. Finally, all the results obtained can only be considered for the research population and conclusions for populations with other characteristics, should not be taken.

In future investigations, will be necessary to use a more representative sample and with another type of population, then we could draw more conclusions. Perhaps, carried out in individuals with training experience to check if even with lower volumes of training could be achieved improvements. It may be interesting to use morphological evaluations to examine the musculoskeletal hypertrophic response to low-volume CT. Could be interesting to create an extra group, who performs even less volume to draw more conclusions about the minimal dose of exercise. Longer investigations may lead to more significant results. However, this remains hypothetical and requires further investigation to elucidate these topics.

Conclusions

The low-volume CT was effective to increase the muscle power of lower limbs, maximal muscular strength in the bench press and back squat, and maximal aerobic capacity without increasing the weekly internal load and with less time spent in exercise than traditional recommendations. The low-volume CT associated with high intensity exercise, can be used as a resource to increase PF and consequently sports performance in several recreational sports which depend on such PF capacities, without increase the psychophysiological stress and consequently, decrease the risk of a state of overtraining, however, more studies are needed to confirm these results. From a practical approach, these results are helpful for coaches or trainers who work with healthy young adults, particularly with less time to spent in exercise or with low weekly availability to exercise, aiming to enhance crucial components of PF, due to the efficacy of this training program in just 6 weeks of low-volume CT.

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Authors contributions

RM and NL conceived of the study. RM managed the database. RM performed statistical analyses. RM and NL interpreted results. RM and NL drafted the manuscript. All authors provided critical reviews and manuscript edits before approval of the final version.

Conflict of interests statement

The authors have no conflicts of interest to report.

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