UNIVERSIDADE ESTADUAL PAULISTA
“JÚLIO DE MESQUITA FILHO”

FLAVIANE POLETO DE OLIVEIRA

DESENVOLVIMENTO DA FORÇA APÓS 12 SEMANAS DE TREINAMENTO SUBSEQUENTE AO EXERCÍCIO AERÓBIO INTERMITENTE DE ALTA INTENSIDADE

Presidente Prudente

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Dissertação apresentada à Faculdade de Ciências e Tecnologia - FCT/UNESP, campus de Presidente Prudente, para obtenção do título de Mestre no Programa de Pós- Graduação em Fisioterapia.

Orientador: Prof. Dr. Fábio Santos de Lira
Co-Orientador: Prof. Dr. Luís Alberto Gobbo

Presidente Prudente
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CERTIFICADO DE APROVAÇÃO

TÍTULO DA DISSERTAÇÃO: Desenvolvimento da força após 12 semanas de treinamento subsequente ao exercício aeróbio intermitente de alta intensidade

AUTORA: FLAVIANE POLETO DE OLIVEIRA
ORIENTADOR: FABIO SANTOS DE LIRA
COORIENTADOR: LUIS ALBERTO GOBBO

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Prof. Dr. FABIO SANTOS DE LIRA
Departamento de Educação Física / Faculdade de Ciências e Tecnologia de Presidente Prudente - SP

Prof. Dr. EDUARDO ZAPATERRA CAMPOS
Departamento de Educação Física / Pós Doutorando do Departamento de Educação Física / Faculdade de Ciencias e Tecnologia de Presidente Prudente - SP

Profa. Dra. VALERIA LEME GONCALVES PANISSA
Pós-doutorado / Universidade de São Paulo

Presidente Prudente, 28 de fevereiro de 2018

Dedicatória

Aos meus pais, Rolmilda e Paulo, ao meu irmão Douglas, a minha madrinha Josefa e aos meus ovós maternos (João e Tereza) e paternos (Raimundo e Lourdes).

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"Primeiro, lembrem-se de olhar para as estrelas lá no alto e não para seus pés lá embaixo. Dois, nunca desistam do seu trabalho. O trabalho lhe dá sentido e propósito, e a vida é vazia sem isso. Três, se você for afortunado a ponto de encontrar amor, lembre-se de que ele está ali e nunca o jogue fora."

Stephen Howking

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1. APRESENTAÇÃO

Esta dissertação é composta de uma introdução, objetivo, métodos e manuscrito escrito na língua inglesa. Os dados foram originados de pesquisas realizadas no Laboratório de Fisiologia Celular do Exercício (LaFiCE), do Departamento de Educação Física da FCT/UNESP – Presidente Prudente. A conclusão foi a partir dos dados obtidos na pesquisa. A dissertação foi redigida de acordo com as regras do Programa de Pós-Graduação em Fisioterapia.

2. RESUMO

INTRODUÇÃO: O Treinamento Concorrente (a combinação de exercício aeróbio com treinamento de força) pode resultar em uma interferência negativa no desempenho de força. Além disso, há indicações de que a magnitude dessa interferência é dependente do modo/intensidade do exercício aeróbio. **OBJETIVO:** Sendo assim, o objetivo deste estudo foi comparar o efeito agudo do Treinamento de Força (TF) e do Treinamento Concorrente (TC) consistidos do Treinamento Intermitente de Alta Intensidade (HIIT) sob os ganhos de força máxima e volume durante 12 semanas. **MÉTODOS:** A amostra foi composta por 19 homens recreativamente ativos divididos entre o grupo TC (n=11) e grupo TF (n=8). O grupo TC realizou o HIIT (1min de corrida a 100% da velocidade aeróbia máxima intercalado por 1min de recuperação passiva até atingir 5 km) e em seguida uma sessão de treinamento de força constituída por oito exercícios com cargas de 8-12 repetições máximas, enquanto o grupo TF realizou apenas as sessões de treinamento de força. Ambos os grupos treinavam duas vezes por semana durante 12 semanas. A força máxima e o volume de treinamento durante uma sessão aguda foram avaliados pré, após oito e 12 semanas de treinamento. **RESULTADOS:** Um pequeno efeito de interferência foi observado na força máxima em relação à massa corporal após 12 semanas de treinamento com maiores melhorias no grupo TF quando comparado ao grupo TC. A mesma não foi observada após oito semanas de treinamento. **CONCLUSÃO:** Esses resultados sugerem que o volume realizado não exerceu impacto nos ganhos de força até oito semanas de treinamento concorrente constituído por HIIT.

Palavras-chave: treinamento intermitente de alta intensidade, força máxima, volume total realizado.

3. ABSTRACT

INTRODUCTION: The concurrent training (i.e., combination of endurance with strength training) may result in negative interference on strength performance. Moreover, there are indications that the magnitude of this interference is dependent on endurance exercise mode. **PURPOSE:** The purpose of this study was to compare maximal strength gains and acute volume performed during strength training (ST) and concurrent training (CT) consisting of high-intensity intermittent training plus strength training over the course of a 12-week intervention. **METHODS:** Nineteen recreationally active males were divided in CT (n=11) and ST (n=8) groups. The CT group performed repeated 1 min efforts at 100% of maximal aerobic velocity interspersed by 1 min of passive recovery until accumulating a total running distance of 5km followed by a strength session (consisting of three sets of eight exercises with loads of 8-12 repetition maximum) twice weekly for a period of 12 weeks, while the ST group performed only strength training sessions. Maximal strength and training volume during an acute exercise session were evaluated at baseline and after eight and 12 weeks of training. A two-way analysis of variance (group and training period) with repeated measures in the second factor was conducted to compare maximal strength values. A three-way analysis of variance (group, training period and set) was conducted to compare the volume performed in the acute exercise sessions. **RESULTS:** A small interference effect was observed in maximal strength relative to body mass after 12 weeks of training with greater improvements in the ST group compared to the CT group, that were not observed after 8 weeks. The volume performed during the acute exercise session was lower in CT than ST after 8 and 12 weeks of training. In summary, executing high-intensity intermittent exercise before strength training impaired the total volume performed after 8 and 12 weeks compared with strength training alone but the impairment of maximal strength occurred only after 12 weeks. **CONCLUSION:** These results suggest that the impairment of volume performed did not have an impact on strength gains until after 8 weeks of concurrent training with high-intensity intermittent exercise.

Key words: high-intensity intermittent training, maximal strength, total volume performed.

4. INTRODUÇÃO

Entre os resultados almejados do treinamento físico regular, força e resistência são as habilidades físicas consideradas mais proeminentes (REILLY et al.,2009). Os exercícios de força são usados para melhorar a capacidade contrátil do músculo esquelético (COSTILL et al., 1979), ao passo que os exercícios aeróbios melhoram o fornecimento de oxigênio do sangue (HOLLOSZY et al., 1984). Assim, o uso de exercícios de força e exercícios aeróbios são comumente empregados para melhorar a aptidão cardiovascular, produção de força e composição corporal (GARBER et al, 2011).

A combinação de exercícios aeróbios com treinamento de força, conhecida como Treinamento Concorrente (TC), vem sendo discutida na literatura científica devido às adaptações antagônicas que esses dois tipos de exercícios podem promover (BELL et al., 2000; HAKKINEN et al., 2003; KRAEMER et al., 1995). Algumas investigações demonstraram que a força máxima e a hipertrofia foram reduzidas após um período de TC em comparação com o treinamento de força isolado, enquanto outras não conseguiram replicar esse tipo de efeito denominado interferência. Assim, esse tema continua sendo o objetivo de investigações recentes.

As causas dessa interferência no ganho de força não estão bem estabelecidas. No entanto, um processo agudo pode ser parcialmente responsável por essa deficiência (CRAIG et al., 1991; LEVERITT et al., 1999). A hipótese aguda sugere que há uma recuperação insuficiente entre as sessões quando o treinamento de força é precedido por atividade aeróbia, demonstrando um decaimento na produção de força. Agudamente, as ocorrências de reduções de força e subsequentes deficiências observadas no trabalho total durante o TC (SALE et al., 1990) podem explicar parcialmente o comprometimento em longo prazo do desenvolvimento da força que depende do volume total realizado (número máximo de repetições e carga determinada) (RHEA et al., 2003).

Na verdade, muitos estudos mostraram decaimento no desempenho de força (número máximo de repetições) quando o exercício aeróbio é realizado antes do exercício de força (INOUE et al., 2016; PANISSA et al., 2015; PANISSA et al., 2012), principalmente, quando o exercício aeróbio é realizado em intensidades mais altas (de SOUZA et al., 2007). A intensidade do exercício é uma variável importante a considerar em relação ao efeito de interferência (DOCHERTY et al., 2000) e aumentou a relevância devida á recente popularidade do treinamento intervalado apetecido como uma estratégia eficiente para aumentar a aptidão aeróbia (de SOUZA et al., 2007) e diminuir a massa gorda (PANISSA et al., 2016)

Poucos estudos testaram se a interferência aguda associada ao TC é responsável pela menor adaptação crônica (EKLUND ET AL., 2015; FYFE ET AL., 2016; SCHUMANN ET AL., 2014). Elklund et al. (2016) e Schumann et al. (2014) compararam diferentes ordens de execução, nas quais, não mostraram efeito de interferência na força máxima ou hipertrofia após 12 e 24 meses de treinamento. No entanto, esses estudos utilizaram o treinamento aeróbio com intensidade moderada, o que favorece a manutenção do volume de treinamento (de SOUZA et al., 2007). Recentemente, Fyfe et al. (2016) demonstraram uma atenuação da força máxima independente da intensidade aeróbia após oito semanas de sessões de treinamento, consistido em exercício aeróbio (intensidades altas e moderadas) seguido de exercício de força, não demonstrando efeito de comprometimento agudo (embora o volume feito não tenha sido relatado). Além disso, no estudo clássico de Hickson et al. (1980) utilizaram um protocolo de exercícios de alta intensidade durante 8 e 10 semanas, no qual, demonstraram uma interferência relacionada ao TC (redução no ganho de força) indicando que as intervenções em longo prazo devem ser considerada.

Contudo, o objetivo deste presente estudo foi comparar o efeito do treinamento de força precedido do HIIT (grupo TC) com ao treinamento de força isolada (grupo TF) sob a força máxima, avaliando a relação entre volume de treino e ganho de força dos membros inferiores sessão por sessão de treinamento após oito e 12 semanas.

ARTIGO

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Maximum strength development and volume-load during concurrent high intensity intermittent training plus strength or strength-only training

Short Title: Concurrent strength training and strength performance

Flaviane Poleto de Oliveira, Fabio Santos Lira*.

1. Exercise and Immunometabolism Research Group, Department of Physical Education, Universidade Estadual Paulista, Presidente Prudente, São Paulo, Brazil.

***Corresponding author**

Fábio Santos Lira, PhD

Address: Departamento de Educação Física, Universidade Estadual Paulista (UNESP) – Presidente Prudente/São Paulo, Brasil. Phone: 55 18 3229-5826, Fax 55 18 3229-5710.

E-mail address: fabiolira@fct.unesp.br

Abstract

The purpose of this study was to compare maximal strength gains during strength training (ST) and concurrent training (CT) consisting of high-intensity intermittent training plus strength training over the course of a 12-week intervention. A secondary purpose was to examine the relationship between strength training volume and strength gain in both groups. Nineteen recreationally active males were divided into CT (n=11) and ST (n=8) groups. The CT group performed repeated 1 min efforts at 100% of maximal aerobic speed interspersed by 1 min of passive recovery until accumulating a total running distance of 5km followed by a strength session (consisting of three sets of eight exercises with loads of 8-12 repetition maximum) twice weekly for a period of 12 weeks. The ST group performed only strength training sessions during the same 12-week period. Strength training total volume-load (Σ repetitions □ load) for the upper- and lower-body was computed, while maximal strength (1RM) was evaluated at baseline, week 8, and week 12. Lower-body volume-load over 12 weeks tended to be lower in CT than ST group (p = 0.053). Absolute 1RM increased in both groups at week 8 and week 12, while 1RM relative to body mass increased in both groups at week 8, but only ST increased maximum strength between week 8 and week 12. There was a significant correlation between strength training lower-body volume-load and maximum strength delta between baseline and week 8 for CT group (r = 0.656). In summary, executing high-intensity intermittent exercise twice a week before strength training did not impair maximal strength up to week 8, subsequently (between week 8 and week 12) only ST demonstrated an increase in relative strength.

Key words: high-intensity intermittent training, maximal strength, total volume performed

Introduction

Among the desired outcomes of regular exercise training, strength and endurance are the most prominent physical abilities considered [36]. Strength training improves skeletal muscle contractile capacity [7], whereas aerobic training improves oxygen delivery to muscle and oxygen extraction from the blood [19]. Thus, both strength and aerobic training programs are commonly employed to improve cardiovascular fitness, force production, and body composition [15].

The combination of aerobic exercise and strength training, known as concurrent training (CT), has received particular focus in the scientific literature due to the potential for antagonistic adaptations [3,17,21] Some investigations have demonstrated that maximum strength was reduced after a period of concurrent training when compared with isolated strength training [3,18,21], while others have failed to replicate this type of interference effect [13,28]. Thus, this topic remains the aim of recent investigations [14,16].

The causes of impairments in strength gains are not well-established; however, an acute process may be partially responsible for this response [8,24]. The acute hypothesis suggests that decrements in force production during resistance training when preceded by aerobic activity are potentially due to insufficient recovery between training sessions and residual fatigue. The acute force reductions and subsequent impairments in total work observed during CT [40] may partially explain the long-term impairment of strength development which may be dependent on the volume of work performed [38].

In fact, many studies have shown performance decrements in strength tasks (maximum number of repetitions) when aerobic exercise is performed prior to strength exercise [20,33,34]. The intensity of exercise is an important variable to consider in relation to the interference effect [11] with larger decrements in strength when aerobic exercise is performed at higher intensities [10]. This topic has increased relevance due to the recent popularity of interval training as an efficient strategy to increase aerobic fitness [30] and decrease fat mass [32].

Few studies have tested if the CT-related decrements in acute strength training volume interfere with long-term adaptations [13,14,41]. However, a recent meta-analysis [31] supports acute volume maintenance as a strategy to minimize interference effects since strength training followed by aerobic exercise order results in superior gains in maximum strength (3.96 kg) compared to the reverse order.

Studies from Elklund et al. [13] and Schumann et al. [41] comparing opposite orders of execution showed no interference effect in maximum strength or hypertrophy after 12 and 24 months of training; however, these studies utilized moderate intensity aerobic training, which favors the maintenance of training volume [De Souza]. More recently, Fyfe et al. [14] showed an attenuation of maximal strength, independent of aerobic intensity, after 8-weeks of training sessions consisting of aerobic exercise (high or moderate intensities) following by strength exercise and reported no effect of acute impairment (although the strength training volume was not reported). Furthermore, a classic study from Hickson et al. [18] utilized a high-intensity exercise protocol for 10 weeks and a CT-related interference (reduction in strength gains) occurred only after the eighth week of training, indicating that long-term interventions must be considered.

Thus, the aim of present study was compare the effect of high-intensity intermittent exercise performed before strength training (CT group) with strength training alone (ST group) on maximum strength after 8 and 12 weeks. A secondary aim was to evaluate the relationship between acute strength training volume and long-term strength gains. We hypothesized that CT would present inferior strength gains compared to ST after 8 and 12 weeks which would be related to lower strength training volume in the CT group.

Materials and methods

Ethics statement

This study was carried out at São Paulo State University (UNESP), Presidente Prudente, SP, Brazil and performed according to the guidelines of the Declaration of Helsinki. The project was approved by the Ethics Research Group of the São Paulo State University (Protocol number: 22793414.7.0000.5402).

Experimental Design

This was an experimental longitudinal study that compared the strength gains and maximal aerobic power to typical training sessions in subjects assigned to either a concurrent training (CT) group or a strength training only (ST) group. Anthropometric, maximal aerobic speed, and maximal strength testing evaluations were performed at baseline, week 8, and week 12 (Figure 1). An additional aerobic evaluation was conducted following four weeks of training in the CT group to allow for intensity adjustments in the high-intensity intermittent training (HIIT) protocol.

Insert Figure 1

Subjects

Inclusion criteria for participation in the study were: 1) participating in systematic strength training during the previous 6 months [1]; 2) age between 18 to 35 years; and 3) considered physically active through aerobic conditioning (minimum twice a week). Exclusion criteria were: 1) contraindications involving the cardiovascular system, muscles, joints, bones of the lower limbs or any musculoskeletal disorders that would limit the participation in strength training; and 2) use of nutritional supplements within the past 6 months (e.g., protein, amino acids, and creatine), prior anabolic steroid use, or use of any other illegal agents known to increase performance for the previous year. All subjects were asked to maintain their usual nutritional habits and to only engage in exercise as proposed by the study protocol. The subjects participated voluntarily in the study after being informed of the procedures, risks, and benefits and signed an informed consent form.

Out of a total of 104 men who participated in the first screening, only 29 met all the inclusion/exclusion criteria and agreed to participate in the study protocol. Participants were randomized into two study groups: CT (n= 15) and ST (n= 14), using simple randomization techniques for allocation, which ensured that trial participants had an equal chance of being allocated to a given treatment group [12]. During the 12 weeks of training, three men dropped out of the study (a dropout rate of 13.6%) and were excluded from the final analyses. The reasons for dropouts included: incompatible schedules, joint problems, unrelated health issues, declined participation, and unspecified reasons or the participants attended fewer than 75% of the training sessions.

Procedures

Anthropometric Assessment

Height was measured using a fixed stadiometer (Sanny brand, São Paulo, Brazil). The participants were barefoot and wore light clothing while standing at the base of the stadiometer, touching their shoulder blades, buttocks and heels to the equipment´s vertical support. Body mass was measured using an electronic scale (Filizola PL 50, Filizzola Ltda., Brazil), with a precision of 0.1 kg.

Maximal Aerobic Speed Test

For determination of maximal aerobic speed, the subjects performed a maximal incremental test on a treadmill (Inbramed-ATL) until voluntary exhaustion. Each stage was composed of 2-min, with the first being performed at a speed of 8 km·h^{-1} followed by 1 km·h^{-1} increases at the end of each stage. In addition, heart rate was registered using a heart rate monitor (Polar Electro, model S810i or RS800, Finland). The maximal speed reached in the test was defined as maximal aerobic speed (MAS). When the subject was not able to finish the 2-min stage, the speed was expressed according to the accumulated time in the final stage, determined as follows: MAS = speed of penultimate stage + [(time, in seconds, remained in the final stage multiplied by 1 km·h^{-1})/120s]. This test was conducted in an isolated session at baseline, week 4, week 8, and week 12 for both groups, and following four weeks in the CT group only. All participants arrived at the laboratory early in the morning and the time of day and environmental conditions (temperature: 22 ± 2ºC) were consistent between testing sessions.

Strength Test Procedures

One week prior to testing, the participants attended three familiarization sessions (Monday, Wednesday and Friday) in which they performed four sets of 12-15 repetitions of each exercise, to become accustomed to the equipment and testing protocols to performed throughout the study [39]. During the subsequent week, approximately 72 hours after the aerobic test, the subjects performed a maximum dynamic strength test consisting of a one repetition maximum (1RM) half-squat using a Smith machine (Ipiranga®, São Paulo/Brazil). The participants performed a five-minute general warm-up on a treadmill at 50% MAS followed by a specific warm-up consisting of 1 set of eight repetitions at 50% 1RM, and 1 set of three repetitions at 80% of 1RM on a Smith machine with 2 min rest between sets. After 3 min rest, subjects had up to five attempts to achieve the 1RM load with rest intervals between three to five minutes [5].

For better control of the 1RM test procedures, the body position and feet placement of each participant in the half-squat exercise were recorded and reproduced throughout the study. In addition, a wooden seat with adjustable heights was placed behind the participant in order to keep the bar displacement and knee angle (~90^o) constant during each half-squat repetition. This test was conducted in an isolated session at baseline, week 8, and week 12 for both groups. All participants arrived at the laboratory early in the morning (between 7 and 9 a.m.) and environmental conditions (temperature: 22 ± 2ºC) were consistent between testing sessions.

Strength and Concurrent Training Protocol

Initially, both groups performed a warm-up on a treadmill at 50% MAS for five minutes with a 1% inclination. The ST group trained two times per week (Monday and Thursday or Tuesday and Friday). The strength training program consisted of three sets with a load at which 8-12 repetitions could be completed and 90 s of rest were provided between sets and exercises. The exercises used in the program were: bench press, half-squat, triceps extension, leg extension, seated row, leg curl and arm curl, and were always performed in this same order. The participants were encouraged to execute at least 8 and no more than 12 repetitions. If more than 12 repetitions were achieved during a session, the load was adjusted to remain in the planned intensity zone.

The CT group also trained two times per week with each session consisting of a HIIT protocol followed by the same strength protocol completed by the ST group. During the HIIT protocol, subjects ran on a treadmill for one minute at 100% MAS interspersed by one minute of passive recovery (without exercise) until they completed 5 km. The number of efforts completed during the HIIT sessions were recorded. A 10-minute recovery period was given between the HIIT and strength protocol. The aerobic test results completed at week 4 and week 8 were used to adjust the intensity.

To ensure that the load and technical aspects of the training protocols were correct, the groups were supervised by professionals who monitored the exercise programs on a daily basis. Participants were instructed to maintain hydration levels and wear appropriate shoes and clothes during training. The strength training total volume-load was calculated by summing the number of repetitions and multiplying by load (Σ repetitions $\times$ load). Volume-load for the lower- and upper-body exercises were evaluated following eight and 12 weeks of training to verify the relationship with maximal strength gains. The entire concurrent exercise session lasted approximately 100 minutes, and the strength training session lasted approximately 50 minutes.

Statistical Analysis

All analyses were performed using the Statistica software package (version 12). Data were reported as means and standard deviation (SD). A Mauchly's test of sphericity was used to test this assumption, and a Greenhouse-Geisser correction was applied when necessary. A two-way analysis of variance (group and training period) with repeated measures in the second factor was conducted to compare maximal strength, maximal aerobic speed, upper-body volume-load, lower-body volume-load, number of efforts completed during HIIT, and the delta of maximal strength and maximal aerobic speed (post minus pre divided by pre multiplied by 100). When a significant main effect or interaction was observed, a Bonferroni post hoc test was applied. Statistical significance was set at $P < 0.05$. Effect sizes for ANOVA were calculated using partial eta squared (η^2), and classified according to Cohen [6] using the following scale for interpretation: < 0.2 [small]; 0.2 to < 0.8 [moderate]; > 0.8 [large]; while effect sizes for post hoc tests were calculated using Cohen'*d* as proposed by Rhea [37] using the following scale (in recreationally trained individuals) for interpretation: <0.35 [trivial]; 0.35 to < 0.80 [small]; 0.80 to < 1.50 [moderate]; > 1.5 [large]. The post hoc effect sizes were presented in the event of statistical significance or when the effect size was large. The correlation between strength training volume-load and strength gains was verified through Pearson correlation coefficients.

Results

Table 1 presents the pre-training subject characteristics. For these variables, we analysed the body mass between groups throughout the training period and no changes were found *(data not shown).*

Insert table 1

Maximal aerobic speed

For maximal aerobic speed (Table 2), there was a main effect for training period ($F_{2,34} = 14.72$; $p < 0.001$; partial $\eta^2 = 0.464$ [moderate] with greater values at week 8 ($p < 0.001$; $d = 0.46$ [small]) and week 12 compared with baseline ($p < 0.001$; $d = 0.60$ [moderate]). For the delta of maximal aerobic speed, there was no interaction or main effects. For the number of efforts completed during HIIT, there was main effect for training period ($F_{2,20} = 22.59$; $p < 0.001$; partial $\eta^2 = 0.693$ [moderate]) with a greater number of efforts between baseline and week 4 (21 ± 2) compared to between week 4 and week 8 (20 ± 2; $p = 0.004$; d = 0.500 [moderate]), and between week 8 and week 12 (19 ± 1; $p = 0.001$; $d = 1.26$ [moderate]).

Insert table 2

Maximal strength

For absolute maximal strength (Table 3), there was a main effect for training period ($F_{1.3,34} = 66.91$; $p < 0.001$; partial $\eta^2 = 0.798$ [large]) with greater values at week 8 and week 12 compared to baseline ($p < 0.001$ for both comparisons; $d = 0.98$

[moderate]; *d* = 1.37 [moderate], respectively) and values at week 8 being less than values at week 12 (p = 0.008; *d* = 0.41 [small]). A large effect size (*d* = 1.51) was shown for the ST group when comparing absolute strength values at baseline and week 12.

For the absolute maximal strength delta values, there was a main effect for training period ($F_{1,17}$ = 6.87; p = 0.018; partial η^2 = 0.287 [small]) with changes between baseline and week 8 being lower than changes between baseline and week 12 (p = 0.018; *d* = 0.58 [small]).

Insert table 3

For maximal strength relative to body mass (Table 4), there was a main effect for training period ($F_{1.5,34}$ = 76.25; p < 0.001; η^2 = 0.818 [large]) with greater values at week 8 and week 12 compared to baseline (p < 0.001 for both; *d* = 0.81 [moderate]; *d* = 1.24 [moderate]) and values at week 8 being less than values at week 12 (p < 0.001; *d* = 0.42 [small]). There was also a trend for a training period and group interaction ($F_{2,34}$ = 3.21; *p = 0.056;* η^2 = 0.155 [small]). For the CT group, lower values were found at baseline compared to week 8 (p < 0.001; *d* = 1.20 [moderate]) and week 12 (p < 0.001; *d* = 1.44 [large]). In the ST group, lower values were found at baseline compared with week 8 (p = 0.003; *d* = 0.597 [moderate]) and week 12 (p < 0.001; *d* = 1.11 [moderate]), and lower values at week 8 compared with week 12 (p = 0.013; *d* = 0.54 [moderate]).

For relative maximal strength delta, there was a main effect of training period ($F_{1,17}$ = 36.97 p < 0.001; η^2 = 0.685 [moderate]) with changes between baseline and week 12 being higher than changes between baseline and week 8 (p < 0.001; *d* = 1.13 [moderate]). There was also an interaction effect ($F_{1,17}$ = 11.62; p = 0.003; η^2 = 0.406 [moderate]; with changes between baseline and week 12 being higher than changes between baseline and week 8 only for ST group (p < 0.001; *d* = 0.877 [moderate]).

Insert table 4

Strength training volume-load

For upper-body volume-load (Figure 2), there was a main effect of training period ($F_{1,17}$ = 715.2 $p < 0.001$; $\eta^2 = 0.978$ [large]), with lower volume-load calculated between baseline and week 8 compared to between baseline and week 12 ($p < 0.001$; *d* = 2.46 [large]. No differences were found between groups.

For lower-body volume-load (Figure 2) there was a main effect of training period ($F_{1,17}$ = 715.2 $p < 0.001$; $\eta^2 = 0.978$ [large], with lower volume-load calculated between baseline and week 8 compared to between baseline and week 12 ($p < 0.001$; *d* = 2.14 [large]). There was a trend for a group effect ($F_{1,17} = 3.49$; $p = 0.069$; $\eta^2 = 0.271$ [small]), with lower volume-load in the CT group compared to the ST group ($p = 0.053$; *d* = 0.604 [moderate]).

Insert figure 2

Correlations

There was a significant correlation (Figure 3) between strength training lower-body volume-load and maximum strength delta between baseline and week 8 for CT group ($r = 0.656$; $p = 0.028$); however, there was no significant correlation for the ST group or the overall group. There was a no correlations between baseline and week 12.

Insert Figure 3

Discussion

To our knowledge, this is the first study to compare the extended effect (8-12 weeks) of high-intensity intermittent exercise performed before strength training with isolated strength training on maximal strength, and its relationship with strength training total volume-load during training. We hypothesized that high-intensity intermittent exercise performed before strength training would decrease strength training volume-load while impairing strength gains following eight and 12 weeks of training. Results from the present study partially refute this hypothesis with similar strength gains between groups following eight weeks and a small impairment in maximal strength relative to body mass in the CT group between week 8 and week 12. Lower-body volume-load also tended to be lesser in CT than ST group over 12 weeks of training.

While impairments in maximal strength relative to body mass, but not absolute strength, were shown during the final 4 weeks of the training intervention in the CT group, a large effect size was observed for absolute strength gains after 12 weeks in the ST group while only moderate effect sizes were shown for the CT group. These data reinforce greater strength gains by ST. While it was expected that the CT group would perform lesser volume throughout the study, we found only a trend towards differences between groups. However, previous research supports acute decrements in training volume during an isolated session [4,10,33,34]. We believe that the alternating lower and upper body exercises performed during the strength training sessions in the current study may have contributed to small differences between groups by allowing additional recovery between exercises and minimizing the detrimental effects of concurrent training.

The acute negative effects of high-intensity aerobic training prior to strength exercise seem to be caused by contractile and metabolic mechanisms [4,20]. Bentley et al. [4] observed that the effects of high-intensity endurance exercise performed before strength exercise can induce excitation-contraction disruptions, synaptic transmission and altered nerve conduction for at least 6 h after exhausting cycling. Further, Inoue et al. [20] investigated the influence of the order of concurrent strength and high-intensity aerobic exercise on strength performance, metabolic, and inflammatory responses using the same protocol as the present study. The authors concluded that when aerobic exercise was followed by strength training, decrements in performance and lower glucose, lactate and higher IL-6 concentrations were observed. Thus, we believe that the

CT group likely experienced residual fatigue throughout the training intervention; however, these potential impairments appear to have resulted in only a slight difference between groups in volume-load.

Controversial results regarding the presence or absence of CT-related interference in strength gains can be found in the literature [21,28]. However, a recent study Fyfe et al. [14] with a similar experimental design, participant characteristics, and objectives (high-intensity intermittent exercise performed before strength training, in physically active men) demonstrated that ST increased maximal strength (38%) more than CT (performed at both high and moderate intensities - 29 and 28% respectively) after 8 weeks of training, indicating an interference effect independent of exercise intensity. These results also refute the impact of strength training volume as the interference effect after 8 weeks of training occurred with the same magnitude using both high and moderate exercise intensity interventions. While it is well documented in the literature that moderate intensity exercise appears to preserve strength training volume [10], Fyfe et al. [14] reported trivial differences in strength gains between CT with the aerobic component performed at moderate and high-intensities while hypertrophy gains were more apparent with ST. Furthermore, Gentil et al [16] demonstrated no interference in strength gains when high-intensity intermittent exercise was performed prior to strength training in premenopausal women after 8 weeks of training, corroborating results from the present study.

Aerobic training volume has been considered an important variable influencing the magnitude of interference effects during CT because both frequency and duration (minutes per day) are negatively correlated with strength gains [44]. The major difference between the present and the above-cited studies involving HIIT [14,16] is the dose/volume of aerobic training. Gentil et al. [16] utilized lower duration high-intensity protocols (6-8 efforts of 60s with 90s of passive rest) performed three times a week, while Fyfe et al. [14] utilized a protocol with slightly greater volume (5-10 efforts of 120s with 60s passive rest) performed three times a week which was similar to the protocol used in the present study (~20 efforts totaling 5km; but training only twice a week). Nonetheless, the volume used in our study was still lower than that used in the seminal study of Hickson et al. [18] which featured alternating high-intensity intermittent and continuous training completed 6 times per week over a period of 10 weeks. Thus, the lack of interference until 8 weeks as found by Gentil et al. [16] and a slight interference between 8 and 12 weeks in the current study likely occurred due to the relatively low volume HIIT programs that were utilized.

Regarding the importance of strength training volume for long-term strength gains, Krieger [22] observed that multiple sets of strength exercises were associated with 46% greater strength gains when compared to one set in both trained and untrained subjects. Furthermore, meta-analyses have shown the importance of training volume with respect to a variety of strength training variables, including the type of sets (cluster or traditional sets) [43], training to failure [9], and the dose-response relationship [38]. On the other hand, Mattocks et al. [27] demonstrated that simply practicing the test repeatedly could increase strength similar to high volume training. Therefore, no consensus has been made regarding the association of between training volume and strength development, particularly in resistance-trained individuals who have already experienced muscular adaptations [35]. Despite only a trend for impaired volume-load in the CT group in the present study, there was a significant relationship between volume-load and maximum strength when data for CT group. Therefore, we hypothesize that a “total volume threshold” may exist in the relationship between strength gain and volume during concurrent training.

Maximal aerobic speed improved throughout the training program with no difference between groups (7.3% for CT and 3.5% for ST after 12 weeks). Although improvement in the ST group was not expected, a recent study also showed an enhancement of the maximal aerobic speed after both strength-only and concurrent training in recreationally active females [23]. This finding could be explained by enhanced efficiency of the neuromuscular system via improved coordination and motor unit recruitment, as well as morphological and musculotendinous stiffness alterations [2]. Improvements in maximal strength may also permit running at a lower relative force resulting in delayed fatigue, and, ultimately, the achievement of higher maximal aerobic speed [42].

There are several factors that could influence individual responses to training, such as intensity, volume, frequency, repetition speed, recovery interval, and training status, as well as, lifestyle and psychological factors [26]. The high variability of the currently examined data may have attenuated some of the interference effect. Despite the importance of our data, some limitations need to be considered: including small sample size, lack of dietary intake control, limited mechanistic evaluation, and no measurement of hypertrophy. Finally, we did not examine the reverse order (strength followed by HIIT) for the CT group or separate training days in order to isolate the impairment on strength training volume-load.

In the present study, physically active men submitted to twice weekly concurrent training (high-intensity intermittent exercise followed by strength exercises) or strength training alone had similar maximal strength gains until the eighth week of training, however, the CT group experienced a small gain of strength between week 8 and week 12 compared with the ST group. These results occurred even with a tendency for lower strength training volume-load in the CT group over 12 weeks, demonstrating that this impairment in volume did not play an important role in the development of maximal strength at least until after completing eight weeks of strength training and HIIT.

Therefore, we suggest future research be conducted to analyze the interference effect over 12 weeks of concurrent training and to further investigate chronic adaptations by manipulating other training variables, such as aerobic training volume or inducing greater impairments in the strength training volume-load given that the interference effect on maximum strength appears to occur in specifically in the context of high volume training [18,44].

The combination of high-intensity intermittent exercise with strength exercises in the same session (aerobic followed by strength), may be employed during training by coaches in order to improve both capacities (aerobic and strength). The use of both types of training (high intensity intermittent aerobic and strength) in a single session provides an alternative to separate sessions, without concern for incomplete recovery and decrements in performance, while allowing for the improvement of relevant health-related capacities.

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Disclosure statement

No competing financial interests exist.

Author Contributions

Conceptualization: Valéria Leme Gonçalves Panissa and Fabio Santos Lira.

Data curation: Valéria Leme Gonçalves Panissa and Fabrício Eduardo Rossi.

Funding acquisition: Fabio Santos Lira.

Investigation: Flaviane Poleto de Oliveira, Sergio Parmezzani Souza, Eduardo Zapaterra Campos.

Methodology: Valéria Leme Gonçalves Panissa, Flaviane Poleto de Oliveira, Sergio Parmezzani Souza, Eduardo Zapaterra Campos, Fabrício Eduardo Rossi, Emerson Franchini, Fabio Santos Lira.

Project administration: Valéria Leme Gonçalves Panissa, Flaviane Poleto de Oliveira, Sergio Parmezzani Souza, Eduardo Zapaterra Campos, Fabrício Eduardo Rossi, Fabio Santos Lira.

Supervision: Valéria Leme Gonçalves Panissa, Emerson Franchini, Fabio Santos Lira.

Writing – original draft: Valéria Leme Gonçalves Panissa, David H. Fukuda, Flaviane Poleto de Oliveira, Sergio Parmezzani Souza, Eduardo Zapaterra Campos, Fabrício Eduardo Rossi, Emerson Franchini, Fabio Santos Lira.

Writing – review & editing: Valéria Leme Gonçalves Panissa, David H. Fukuda, Emerson Franchini and Fabio Santos Lira.

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Figures captions

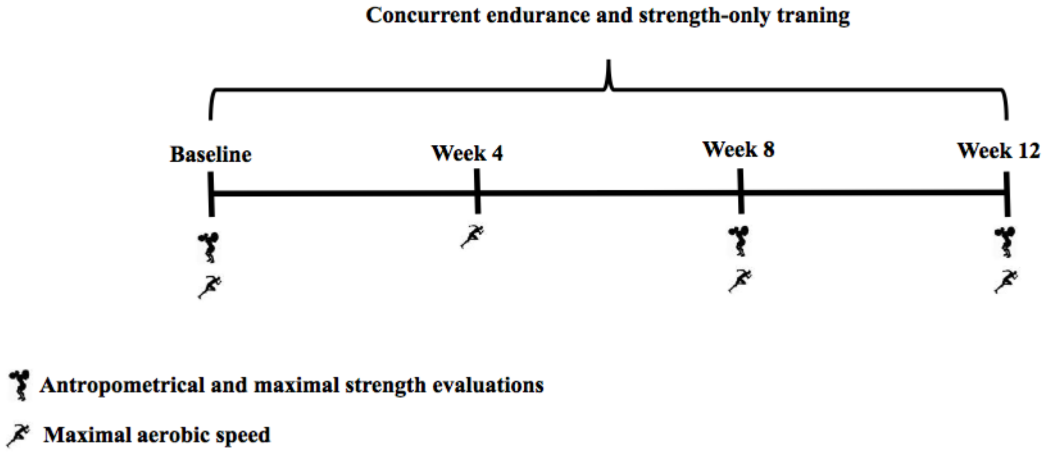

Figure 1: Study design.

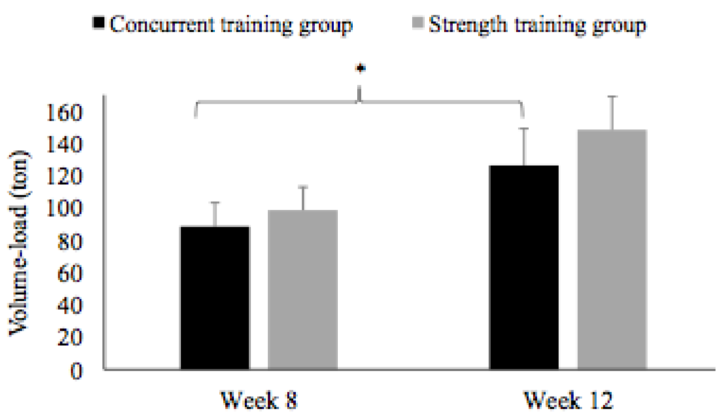

Figure 2. Strength-training volume-load during strength training only (ST) or high-intensity intermittent training plus strength training (CT). **Note:** data are mean ± standard deviation. * = trend to be lower than ST (p = 0.053).

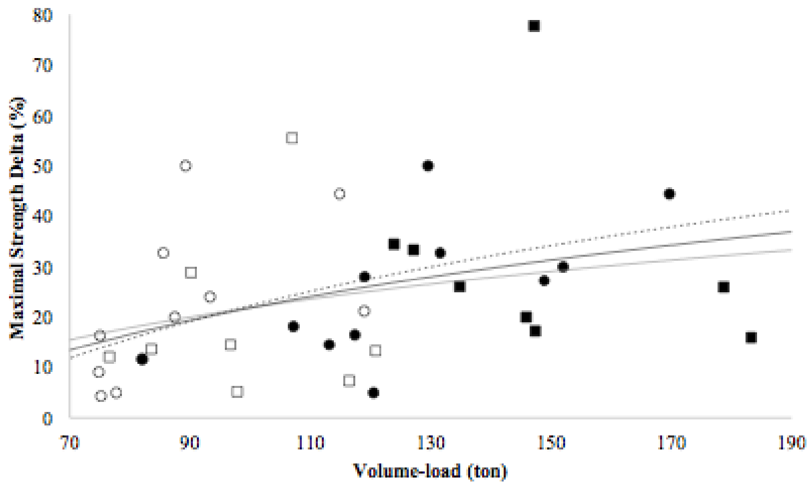

Figure 3. Relationships between changes in maximal strength delta and volume-load at week 8 and week 12 for the ST and CT groups. **Note:** ◦: CT group week 8 data; •: CT group week 12 data; □: ST group week 8 data; ■: ST group week 12 data; solid trend line: overall group; dashed trend line: ST group; grey trend line: CT group. There was a correlation between volume-load performed and delta maximum strength gains in 8 weeks for CT group isolated ($p = 0.028$; $r = 0.645$).

Table 1: General characteristics of the sample from baseline.

	Concurrent training Group (n = 11)	Strength Training Group (n = 8)
Age (years)	24.5 ± 3.7	28.7 ± 3.4
Body mass (kg)	74.6 ± 6.8	77.5 ± 12.9
Height (cm)	179.4 ± 7.0	177 ± 7.7

Table 2. Maximal aerobic speed during strength training only (ST) or high-intensity intermittent training plus strength training (CT).

	Maximal aerobic speed ($km.h^{-1}$)		Delta from Baseline (% change)	
	ST	CT	ST	CT
Baseline	13.2 ± 1.7*	14.1 ± 1.3*	-	-
Week 8	13.5 ± 1.4	14.9 ± 1.1	2.3 ± 3.1	6.0 ± 4.0
Week 12	13.6 ± 1.3	15.1 ± 1.0	3.5 ± 7.3	7.3 ± 5.4

Note: data are mean ± standard deviation; * = different from week 8 and 12 ($p < 0.05$).

Table 3. Lower-body absolute maximal strength during strength training only (ST) or high-intensity intermittent training plus strength training (CT).

	Absolute maximal strength (kg)		Delta from Baseline (% change)	
	ST	CT	ST	CT
Baseline	121 ± 24*	113 ± 22*	-	-
8 weeks	141 ± 19#	136 ± 24#	19 ± 16£	21 ±15£
12 weeks	157 ± 23	141 ± 28	31 ± 18	25 ± 13

Note: data are mean ± standard deviation; * = different from week 8 and 12 ($p < 0.05$); # = different from week 12 ($p < 0.05$); £ = different from delta week 12 ($p < 0.05$).

Table 4. Lower-body relative maximal strength during strength training only (ST) or high-intensity intermittent training plus strength training (CT)

	Relative maximal strength (kg/kg of body mass)		Delta from Baseline (% change)	
	ST	CT	ST	CT
Baseline	1.61 ± 0.45*	1.51 ± 0.25*	-	-
Week 8	1.87 ± 0.42#	1.80 ± 0.27#	18 ± 14£	20 ± 16
Week 12	2.10 ± 0.43	1.87 ± 0.29	34 ± 18	25 ± 14

Note: data are mean ± standard deviation; * = different from week 8 and 12 ($p < 0.05$); # = different from week 12 ($p < 0.05$); £ = different from delta week 12 ($p < 0.05$).

6. CONCLUSÃO

Tomados em conjunto, os resultados encontrados na presente dissertação demonstra que homens fisicamente ativos submetidos ao treinamento concorrente duas vezes por semana (exercício intermitente de alta intensidade seguido de exercícios de força) ou o treinamento de força isolado exibiram ganhos de força máxima similares até a oitava semana de treinamento, no entanto, o grupo treinamento concorrente experimentou um pequeno ganho de força entre a semana 8 e a semana 12 em comparação com o grupo treinamento de força isolado. Estes resultados ocorreram mesmo com menor volume (tendência) de carga realizado pelo grupo treinamento concorrente em 12 semanas, demonstrando que esse comprometimento no volume de treino não desempenhou um papel importante no desenvolvimento da força máxima, pelo menos até completar oito semanas de treinamento de força subsequente ao HIIT.

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