High intensity interval running impairs subsequent upper limb strength performance

Concurrent HIIT on treadmill and upper limbs

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Abstract

BACKGROUND: This study compared the effect of treadmill running on subsequent upper limb exercise performance in young men.

METHODS: Seventeen young men (24.8±5.2 years) completed a (1) bench press resistance exercise control session; (2) treadmill interval running protocol followed by the bench press session; (3) treadmill continuous running protocol followed by the bench press session. Four sets of the bench press exercise were performed at 80% of 1RM up to volitional failure. In the interval protocol, eight sprints of 40s at 100% of the velocity of maximal oxygen uptake, with 20s of passive interval between them were performed, whereas in the continuous protocol 30-min of treadmill running at 90% of the heart rate corresponding to second ventilatory threshold was performed. The number of maximal repetitions completed in each set and condition was recorded and compared using a two-way repeated measures ANOVA.

RESULTS: The interval protocol (18.7 ± 4.9 repetitions) resulted in a reduction in the number of bench press repetitions compared to the control protocol (21.4 ± 5.4 repetitions) ($p=0.002$); whereas continuous running did not affect the bench press performance (20.6 ± 4.4 repetitions). The total number of repetitions reduced from set to set in all protocols ($p<0.001$).

CONCLUSION: The results evidenced an impairment in the upper limb strength performance after high intensity interval, but not moderate intensity continuous running, which has implication for concurrent training planning and prescription.

KEY WORDS: High intensity interval training – Exercise - Muscle Strength – Resistance training.

Introduction

Cardiorespiratory capacity and muscular strength are important physical fitness components for both health and performance[1,2]. Thus, aerobic and strength exercises are commonly performed in the same session (i.e. concurrent training). Existing evidence suggests that performing aerobic exercise followed by the strength component of concurrent training may cause interference in neuromuscular adaptations when compared to strength training performed in isolation[3]. Regarding the hypotheses suggested to explain the concurrent training interference effect on strength development, the “acute hypothesis” suggests that residual fatigue from the previous aerobic exercise could bring about an acute reduction in strength capacity, impairing the quality of the subsequent strength exercise session[4].

Previous studies have investigated the acute effect of aerobic exercise sessions performed prior to assessing strength exercise performance[5–13]. Some training variables, thought to influence the acute interference effect, were compared, such as the aerobic exercise intensity, stimulus (i.e. continuous or interval)[7–9], aerobic exercise volume[12], mode of aerobic exercise (i.e. treadmill or cycle ergometer)[11], different rest periods[9,10] and muscular groups engaged in both the aerobic and strength exercises[6–9].

It has been evidenced that a decrease in the lower limb strength performance occurs after continuous and interval aerobic protocols[6–13]. This impairment may be explained by muscle damage and lower limb fatigue that may be developed during the aerobic exercise session, since the same muscular group is recruited in the subsequent strength activity. On the other hand, current literature reports no impairment in upper limb strength performance after running[5,7,8] or cycling[6,9] endurance protocols.

In relation to aerobic exercise prescription, high intensity interval training (HIIT) has been shown to increase individuals' cardiorespiratory fitness[14–16]. HIIT is characterized by efforts of the higher intensity interspaced by rest periods[17]. De Souza et al.[7] and De Salles Painelli et al.[8] investigated the effects of continuous versus interval running on a treadmill on subsequent upper limbs strength performance. The protocols employed in both studies had similar distance (i.e., 5 km) and duration (i.e., ≈ 50 min), but differed in terms of exercise intensity. Both continuous (90% of the velocity associated to anaerobic threshold) and interval aerobic exercise (1 min of effort at 100% of the velocity associated to maximal uptake oxygen and 1 min of passive rest, 1:1 effort to rest ratio – E:R) demonstrated no impact on subsequent upper limb strength performance (1 or 4 sets at 80% of one repetition maximum - 1RM).

Interval protocols with short duration and high intensity have been used to the development of the cardiorespiratory fitness because its time-efficient nature[18]. Considering the total duration of the combined training session, interval protocols with this characteristic may be an alternative to decrease the session time. However, studies investigating interval protocols used E:R of 1:1, and it is not clear whether running sessions with different effort to rest ratio could impair subsequent upper limb strength performance. High intensity interval protocols have gained popularity between the general population and longer effort to rest ratios are also employed in practice. Therefore, this study was designed to investigate whether high intensity interval running employing a 2:1 effort to rest ratio acutely impairs subsequent upper limb strength performance.

In addition, none of the studies reported[5–13] investigated metabolic parameters during the concurrent training sessions with aerobic interval and upper limbs strength exercises. Moreover, the total volume load of exercise should also be considered since it is an important variable that influence in strength production capacity[19,20]. These outcomes may help to understand the acute impact of different types of protocols on exercise subsequent resistance exercise performance and expand the around concurrent training prescription.

In this sense, the combination of the lower limb aerobic and upper limb strength exercises in the periodization of a training program may be an alternative to avoid the interference effect[21,22]. Therefore, it becomes relevant to assess whether the interference effect caused by interval aerobic protocols with these characteristics (E:R different, i.e., 2:1) on upper limb strength exercise performed subsequently. Thus, the aim of the present study was to compare effect of a continuous and an interval running protocol on the number of maximal repetitions of completed during upper limb strength exercise performed at 80% of 1RM in young men. The secondary purpose was to compare participants' heart rate (HR) and blood lactate concentration ([lac]) between protocols.

Material and methods

Participants

Seventeen healthy young men (24.8 ± 5.2 years) with at least six months of experience in strength training volunteered for the study (Table I). Exclusion criteria included tobacco use, and any history of neuromuscular, metabolic, endocrine, and cardiorespiratory diseases. The study was approved by the Local Ethics Research Committee (registration number 54531816.4.0000.5313). All participants were informed about the research procedures and signed an informed consent before taking part in the study.

Experimental design

Participants were required to make five visits to the laboratory, with at least 48 h of rest between them, and were instructed to not perform vigorous exercise and abstain from caffeine or other stimulants in the previous 24 h of each visit. In the first visit, they performed a maximal incremental test on a treadmill. In the second visit their bench press 1RM was determined. The next three visits were used to investigate the influence of two treadmill running protocols (i.e. continuous or interval) on subsequent upper-limb strength performance. To this end, two experimental sessions were conducted in which a treadmill interval protocol was followed by a bench press exercise and a treadmill continuous protocol was followed by the bench press exercise. While in the control session, the bench press was performed alone. The number of repetitions in each set of the bench press exercise was assessed in all experimental sessions.

Procedures

Maximal treadmill incremental test

The maximal incremental test was performed using a treadmill (Arktus, Santa Tereza do Oeste, Brazil) to determine the heart rate (HR) equivalent to the second ventilatory threshold and the velocity corresponding to the VO_{2max} (vVO_{2max}). The test started at 6 $km.h^{-1}$ for 2 min and velocity was increased progressively at 1 $km.h^{-1}$ each minute until exhaustion. The test was finished when the participant indicated exhaustion. Respiratory gases were collected using a mixing-box-type portable gas analyzer (VO2000; MedGraphics, Ann Arbor, USA), previously calibrated according to the manufacturer's specifications. Sampling rate was set at 1 sample for every 3 breaths, and data was stored in the Aerograph software (MedGraphics, Ann Arbor, USA). During the incremental test, HR was recorded every 30 s with a HR monitor (FS1, Polar, Kempele, Finland), and the test was considered maximal when at least two of the following criteria were met: predicted maximal heart rate was reached (220-age), a respiratory exchange ratio greater than 1.15 was observed, or a maximal respiratory rate of at least 35 breaths per minute[23]. The vVO_{2max} was defined as the velocity of the last stage complete during the test. The second ventilatory threshold was determined using the ventilation-workload slope, and was confirmed through the slope of the ventilatory equivalent of VCO_2 (V_E/VCO_2)[24]. Blinded analysis was performed by two independent researchers and a third researcher was consulted in case of disagreement.

Maximum dynamic strength test

In the previous session (i.e. maximal treadmill test) the participants performed familiarization with 1RM range of motion and movement cadence (i.e. 2 s for each contraction phase – concentric and eccentric) used in the next sessions. For this, two sets with 10-15 repetitions were performed in the bench press exercise, with load of the 28 kg. Participants performed a 5 min general warm-up in a cycle ergometer and a specific warm-up in the bench press (NEW FITNESS, São Paulo, Brazil) exercise with a submaximal load. Initial 1RM testing load was based on participants' experience, and each subject performed the maximal number of repetitions (up to a maximum of 10) in each trial. When more than one repetition could be completed, the new testing load was adjusted according to Lombardi's equation[25] for the following trial. A maximum of five attempts were performed, with 4 min of rest interval between each trial. The bench press movement cadence was controlled with assistance of a digital metronome (MA-30, KORG, Japan), so that each repetition was completed in approximately 4 s (2 s for concentric phase, and 2 s for eccentric phase). The bench press 1RM was then defined as the highest load the participant could lift within the determined range of motion and movement cadence.

Experimental Protocols

The three following sessions were randomized at: 1) control protocol, wherein the participants performed only bench press exercise; 2) running interval protocol previous to bench press exercise; and 3) running continuous protocol previous to bench press exercise. In all sessions participants were kept sitting in a calm environment during 10 min and then resting HR and blood lactate concentration [lac] were measured. Blood samples (15 μl) were taken from the ear lobe using disposable lancets and reagent strips (Roche, São Paulo, Brazil) and the analyses were performed in real time using a portable lactate analyzer (Accutrend Plus, Mannheim, Germany).

Control session. After a warm-up of 5 min at 6 $km.h^{-1}$, participants rested for two minutes and performed four sets of bench press, completing the maximal number of repetitions per set at 80% of 1RM, with 2 min of interval between them. Each set was stopped at concentric failure or when the exercise could no longer be performed at the pre-stipulated cadence (i.e., 2 s by contraction phase).

Experimental sessions. After the warm-up described above, participants' performed either a) an interval protocol consisting of eight bouts of 40 s at 100% of vVO_{2max}, with 20 s of passive rest between them; or b) 30 min running on the treadmill at ± 5 bpm of 90% HR equivalent to their second ventilatory threshold (HR_{VT2}). After 5 min of rest participants performed the bench press protocol described previously. The high intensity interval protocol was selected based on Buchheit and Laursen[17] study. The interval protocol was designed to be feasible and time-efficient in comparison to protocols used in other studies. In addition, the present study employed the same intensities used by De Souza et al.[7] and

De Salles Painelli et al.[8], with a different E:R, which is the justification of the study. The continuous protocol was performed at 90% HR_{VT2}, which was chosen to allow participants to exercise for an extended period of time at a well-controlled intensity.

In all protocols the number of repetitions completed in each set were registered. Total work was calculated based on the product of total number of repetitions and load. HR and [lac] were obtained at baseline, 1 min prior the first set of the strength exercise, and immediately after the fourth set of the strength exercise.

Statistical analyses

Data are presented as mean ± standard deviation. The Shapiro-Wilk test was used to test data normality. A repeated measures one-way ANOVA was performed to compare HR and [lac] at rest between three sessions and to compare the total work between protocols. A repeated measures two-way ANOVA was used for comparing protocol and set main effects on the number of repetitions and for comparing protocol and time-point main effects on HR and [lac], using Bonferroni post hoc whenever necessary. In addition, when the interaction was significant, the main factors were tested again using the Bonferroni post hoc tests. The effect size (Cohen's d) was calculated from the mean values of repetitions and total work between continuous and interval protocols versus control, and classified as small (between 0.2 and 0.5), moderate (between 0.5 and 0.8), or large (0.8 or more)[26]. The significance level adopted in this study was □ = 0.05. All statistical tests were performed in the SPSS vs. 20.0.

Results

The number of repetitions performed in each set of bench press exercise during the three experimental conditions is presented in the Figure 1. A significant main effect was observed for study protocol, with the interval protocol resulting in smaller number of repetitions in comparison to the control protocol ($p = 0.002$). No significant difference was observed between the continuous and the other protocols. In addition, significant main effect for exercise set was found ($p < 0.001$), with difference in the number of repetitions among throughout the four sets in all protocols ($p < 0.001$). No significant interaction between protocol and exercise set was observed ($p = 0.114$).

When the total number of repetitions (sum of repetitions during the four sets) and total work performed during the bench press exercise were analyzed an significant influence of experimental condition was observed, with the interval protocol resulting in less repetitions and total work performed (number of repetitions: -13%; total work: -13%; Figure 2) in comparison to the control protocol, whereas results from the continuous protocol did not differ from the others (control = 21.4 ± 5.4 repetitions and 1757.8 ± 499.3 repetitions x Kg; interval = 18.6 ± 4.8 repetitions and 1533.8 ± 435.7 repetitions x Kg; continuous = 20.6 ± 4.4 repetitions and 1694.8 ± 413.2 repetitions x Kg; $p = 0.002$).

Effect size analysis between interval and control protocols indicated moderate effect in the sets 2 (0.61; 95% CI from -0.08 to 1.30) and 3 (0.53; 95% CI from -0.16 to 1.21) and in the total number of repetitions (0.51; 95% CI from -0.17 to 1.20), whereas small effect was found in sets 1 (0.41; 95% CI from -0.27 to 1.09) and 4 (0.27; 95% CI from -0.40 to 0.95) and total work (0.47; 95% CI from -0.21 to 1.15). Furthermore, continuous exercise and control protocol comparisons indicated small effect in set 1 (0.41; 95% CI from -0.27 to 1.09), set 2 (0.40; 95% CI from -0.28 to 1.08) and set 3 (0.26; 95%

CI from -0.42 to 0.93), whereas no effect was observed in set 4 (0.07; 95% CI from -0.60 to 0.75), and total number of repetitions (0.15; 95% CI from -0.52 to 0.82) as well as total work (0.13; 95% CI from -0.54 to 0.81).

At baseline, HR (control: 67.7 ± 10.7 bpm; interval: 68.1 ± 7.8 bpm; continuous: 67.5 ± 7.8 bpm; $p = 0.942$) and [lac] (control: 2.0 ± 0.8 $mmol.l^{-1}$; interval: 2.1 ± 0.6 $mmol.l^{-1}$; continuous: 1.9 ± 0.8 $mmol.l^{-1}$; $p = 0.620$) values were similar among the three protocols. HR and [lac] before strength exercise and immediately post the last set in the three protocols are presented in Table II.

A significant interaction between protocol and timepoint was evident for both HR and [lac] ($p < 0.001$ and $p = 0.004$, respectively). The Bonferroni post hoc analysis indicated that the participants' HR increased after the control session and reduced after bench press performance in the continuous and interval protocols, whereas the participants' [lac] increased after all protocols. HR and [lac] values pre strength exercise were significant different between all the protocols. The interval protocol showed the highest values, followed by the continuous protocol, and the control session showed the lowest values. In addition, HR post bench press exercise was higher in both interval and continuous protocols compared to the control session. [lac] post bench press exercise resulted in higher values in the interval protocol compared to the others.

Discussion

The main findings of the present study were a reduction in the number of repetitions performed in the bench press exercise when preceded by a whole body (i.e. running) interval aerobic exercise (E:R = 2:1), whereas a continuous protocol did not impair upper limb strength exercise performance. In addition, a decrease was observed in the number of repetitions throughout the four sets of the bench press exercise in all the protocols. It should be highlighted that the high intensity of the interval aerobic exercise based on the higher HR and [lac] values at the pre strength exercise (i.e., immediately after the interval or continuous aerobic exercise), which were remained elevated up to the last set of the strength exercise.

Acute effects of lower body aerobic protocols on upper limb strength performance have been investigated in previous studies[5–9]. The findings of the present study regarding continuous and control protocols corroborate the Raddi et al.[5] and Reed et al.[6], since both studies did not report a decrease in bench press performance at after continuous treadmill aerobic exercise (45 min 70-75% HR_{max}) and cycle ergometer (45 min 75% HR_{max}). Based on these results, the authors concluded that, independent of the protocol or ergometer used, the continuous aerobic exercise does not seem to influence the upper limbs strength performance.

On the other hand, in disagreement to De Souza et al.[7] and De Salles Painelli et al.[8], the present study found a decrease in the number of repetitions throughout the four sets of bench press exercise post interval aerobic protocol, while the previous studies found no impairment in the upper limb strength performance after both continuous and interval aerobic protocols[7,8]. Such studies observed a maintenance in the number of maximal repetitions in the bench press exercise post a 5-km treadmill run at 90% of velocity associated to the anaerobic threshold, and post a 5-km treadmill run with 1 min of effort at 100% vVO_{2max} and 1 min of passive rest, totaling ≈ 50 min[7,8]. These different results regarding interval aerobic exercise may be associated to the distinct interval training protocols employed in the studies. The running interval exercise in the present study was composed by eight sprints of 40 s at 100% vVO_{2max} with 20 s passive rest, for a total of 8 min. Although similar exercise intensity was used, the different effort and rest intervals in the current study resulted in greater E:R (i.e., 2:1) in comparison to the protocols of the others studies (i.e., 1:1). In addition, differences such as the time of interval between the strength and aerobic exercises[7,8] may have influenced the observed results. While in the present study 5 min of rest was given between the aerobic and the bench press exercise, De Souza et al.[7] and De Salles Painelli et al.[8] employed ≈ 30 min of rest interval because the authors also investigated the running effects on the lower limbs strength performance prior to assessing the upper limbs strength.

Since running and bench press engage different muscle groups, it is possible that the impairment in the strength performance post interval protocol may not be related to the local peripheral fatigue, but potentially central adjustment generated by the high intensity of the previous aerobic exercise[27]. In accordance with others, fatigue in muscles of the locomotor apparatus may inhibit corticospinal activation, and then possibly hamper the activation and performance non-exercised muscles, such as those from the upper limbs in the present study[28].

The high effort generated by the interval protocol was confirmed by HR and [lac] values recorded before the strength exercise (control: 67.7 ± 10.7 bpm and 2.0 ± 0.8 $mmol.l^{-1}$; continuous: 169.0 ± 6.8 bpm and 3.1 ± 1.3 $mmol.l^{-1}$; interval: 185.6 ± 7.1 bpm and 5.8 ± 1.4 $mmol.l^{-1}$), since they were higher after the interval protocol, suggesting a greater physiological stress in this experimental protocol compared to the others. Such findings for [lac] are similar to those reported by Reed et al.[6], who found [lac] of 2.49 ± 1.57 $mmol.l^{-1}$ post continuous cycle ergometer, and by Leveritt and Abernethy[13], who reported values of 6.16 ± 2.28 $mmol.l^{-1}$ 25 min post a cycle ergometer interval session. Thus, the decrease in bench press performance after the interval protocol may be a result of higher level of whole body fatigue.

It is important to note that this study is not free from limitations. First, it is unlikely that the running protocols employed are equivalent regarding to energy expenditure and total work. Second, the present results should not be extrapolated to different populations (e.g. elderly, untrained individuals, and athletes), others continuous or interval aerobic protocols and mode of aerobic exercise (e.g. cycle ergometer).

Conclusions

In summary, ours results indicate that an impairment in the upper limb strength performance may be expected 5 min after the performance of an interval running but not post a moderate intensity continuous protocol, suggesting high intensity interval exercise may compromise strength exercise performed subsequently. In this sense, the prescription of a training program combining aerobic exercise and upper limbs strength exercises should take in consideration the nature of the aerobic performed prior the strength exercise component of the training session. Alternatively, one may consider adding one or two sets of the strength exercise, if the aim is to maintain a high total work or strength exercise volume.

Authors' contribution

LSA and GBD contributed to study concept and design, and drafting of the manuscript. VLK contributed to acquisition of data and drafting of the manuscript. LSA, GBD and CLA contributed to analysis and interpretation of data. ENW and CLA contributed to critical revision of the manuscript for important intellectual content. All authors read and approved the final version of the manuscript.

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References

1. Haskell WL, Kiernan M. Methodologic issues in measuring physical activity and physical fitness when evaluating the role of dietary supplements for physically active people. Am J Clin Nutr 2000;72(2 Suppl):541S-50S.
2. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I-M, et al. Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults. Med Sci Sport Exerc 2011;43:1334–59.
3. Wilson JMC, Marin PJ, Rhea MR, Wilson SMC, Loenneke JP, Anderson JC. Concurrent Training: A Meta-Analysis Examining Interference of Aerobic and Resistance Exercises. J Strength Cond Res 2012;26:2293–307.
4. Leveritt M, Abernethy PJ, Barry BK, Logan PA. Concurrent Strength and Endurance Training. Sport Med 1999;28:413–27.
5. Raddi LLO, Gomes RV, Charro MA, Bacurau RFP, Aoki MS. Treino de corrida não interfere no desempenho de força de membros superiores. Rev Bras Med do Esporte 2008;14:544–7.
6. Reed JP, Schilling BK, Murlasits Z. Acute Neuromuscular and Metabolic Responses to Concurrent Endurance and Resistance Exercise. J Strength Cond Res 2013;27:793–801.
7. De Souza EO, Tricoli V, Franchini E, Paulo AC, Regazzini M, Ugrinowitsch C. Acute Effect of Two Aerobic Exercise Modes on Maximum Strength and Strength Endurance. J Strength Cond Res 2007;21:1286-90.
8. De Salles Painelli V, Alves VT, Ugrinowitsch C, Benatti FB, Artioli GG, Lancha AH, et al. Creatine supplementation prevents acute strength loss induced by concurrent exercise. Eur J Appl Physiol 2014;114:1749–55.

9. Sporer BC, Wenger HA. Effects of Aerobic Exercise on Strength Performance Following Various Periods of Recovery. J Strength Cond Res 2003;17:638-44.

10. Panissa VLG, Ferreira Julio U, Pinto e Silva C, Vidal Andreato L, Hardt F, Franchini E. Effects of interval time between high-intensity intermittent aerobic exercise on strength performance: analysis in individuals with different training background. J Hum Sport Exerc 2012;7:815–25.

11. Panissa VLG, Tricoli VAA, Julio UF, Ribeiro N, de Azevedo Neto RMA, Carmo EC, et al. Acute Effect of High-Intensity Aerobic Exercise Performed on Treadmill and Cycle Ergometer on Strength Performance. J Strength Cond Res 2015;29:1077–82.

12. Ribeiro N, Ugrinowitsch C, Panissa VLG, Tricoli V. Acute effects of aerobic exercise performed with different volumes on strength performance and neuromuscular parameters. Eur J Sport Sci 2019;19:287–94.

13. Leveritt M, Abernethy PJ. Acute Effects of High-Intensity Endurance Exercise on Subsequent Resistance Activity. J Strength Cond Res 1999;13:47–51.

14. Schaun GZ, Pinto SS, Silva MR, Dolinski DB, Alberton CL. Whole-Body High-Intensity Interval Training Induce Similar Cardiorespiratory Adaptations Compared With Traditional High-Intensity Interval Training and Moderate-Intensity Continuous Training in Healthy Men. J Strength Cond Res 2018;32:2730–42.

15. Batacan RB, Duncan MJ, Dalbo VJ, Tucker PS, Fenning AS. Effects of high-intensity interval training on cardiometabolic health: a systematic review and meta-analysis of intervention studies. Br J Sports Med 2017;51:494–503.

16. Milanović Z, Sporiš G, Weston M. Effectiveness of High-Intensity Interval Training (HIT) and Continuous Endurance Training for VO2max Improvements: A Systematic Review and Meta-Analysis of Controlled Trials. Sport Med

2015;45:1469–81.

17. Buchheit M, Laursen PB. High-Intensity Interval Training, Solutions to the Programming Puzzle. Sport Med 2013;43:927–54.

18. Gillen JB, Gibala MJ. Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness? Appl Physiol Nutr Metab 2014;39:409–12.

19. Robbins DW, Marshall PW, McEwen M. The Effect of Training Volume on Lower-Body Strength. J Strength Cond Res 2012;26:34–9.

20. Sooneste H, Tanimoto M, Kakigi R, Saga N, Katamoto S. Effects of Training Volume on Strength and Hypertrophy in Young Men. J Strength Cond Res 2013;27:8–13.

21. Docherty D, Sporer B. A proposed model for examining the interference phenomenon between concurrent aerobic and strength training. Sports Med 2000;30:385–94.

22. Fyfe JJ, Bishop DJ, Stepto NK. Interference between Concurrent Resistance and Endurance Exercise: Molecular Bases and the Role of Individual Training Variables. Sport Med 2014;44:743–62.

23. Howley ET, Bassett DR, Welch HG. Criteria for maximal oxygen uptake: review and commentary. Med Sci Sports Exerc 1995;27:1292–301.

24. Wasserman K, Whipp BJ, Koyl SN, Beaver WL. Anaerobic threshold and respiratory gas exchange during exercise. J Appl Physiol 1973;35:236–43.

25. Lombardi VP. Beginning weight training: the safe and effective way. Dubuque: W.C. Brown; 1989.

26. Cohen. Statistical power analysis for the behavioral sciences. 2ed. New York: Laurence Erlbaum Associates; 1988.

27. Decorte N, Lafaix PA, Millet GY, Wuyam B, Verges S. Central and peripheral

fatigue kinetics during exhaustive constant-load cycling. Scand J Med Sci Sports 2012;22:381–91.

28. Sidhu SK, Weavil JC, Venturelli M, Garten RS, Rossman MJ, Richardson RS, et al. Spinal μ-opioid receptor-sensitive lower limb muscle afferents determine corticospinal responsiveness and promote central fatigue in upper limb muscle. J Physiol 2014;592:5011–24.

Table I. Participants' characteristics.

Variable	**Mean ± SD**
Age (years)	24.8 ± 5.2
Body mass (kg)	78.5 ± 11.9
Height (cm)	177.0 ± 7.0
Body mass index ($kg.m^{-2}$)	25.0 ± 3.1
HR_{max} (bpm)	193.2 ± 6.4
VO_{2max} ($ml.kg^{-}1.min^{-1}$)	61.7 ± 10.5
vVO_{2max} ($km.h^{-1}$)	15.4 ± 0.9
Bench press 1RM (kg)	83.8 ± 18.5

HR_{max}, maximal heart rate; VO_{2max}, maximal oxygen uptake; vVO_{2max}, maximal velocity of VO_{2max}; 1RM, one repetition maximum.

Table II. Heart rate (HR) and blood lactate concentration [lac] pre and post bench press exercise in the control, interval and continuous protocols.

		Pre	Post	Protocol	Moment	Protocol*Moment
HR (bpm)	Control	67.7 ± 10.7 [a]	121.3 ± 20.9 *[a]	< 0.001	0.054	< 0.001
	Continuous	169 ± 6.8 [b]	139.1 ± 14.1 *[b]			
	Interval	185.6 ± 7.1 [c]	142.8 ± 11.4 *[b]			
[lac] ($mmol.l^{-1}$)	Control	2.0 ± 0.8 [a]	5.1 ± 1.0 *[a]	< 0.001	< 0.001	0.004
	Continuous	3.1 ± 1.3 [b]	5.0 ± 1.3 *[a]			
	Interval	5.8 ± 1.4 [c]	6.8 ± 1.4 *[b]			

*Significant difference between pre and post bench press exercise; Different letters indicate significant differences between protocols ($p < 0.05$).

FIGURE CAPTIONS

Figure 1. Number of maximal repetitions completed in each set of the bench press exercise during the three experimental conditions (mean ± SD). *Significant difference between control and interval protocol; Different letters indicate significant differences between sets in all protocols.

Figure 2. Total number of maximal repetitions (A) and total work (B) of bench press exercise performed during the three experimental conditions (mean ± SD). *Significant difference between control and interval protocol.