©Journal of Sports Science and Medicine (2011) **10,** 565-570
http://www.jssm.org

Research article

The acute effects of varying strength exercises bouts on 5km running

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Abstract

This study investigated if there were acute interference effects of strength exercises on subsequent continuous and intermittent 5Km aerobic exercises. Eleven physically active males (23.1 ± 3.1 yrs, 1.75 ± 0.07 m, 70.5 ± 8.8 kg, and 58.2 ± 8.3 VO_2max) performed the following experimental sessions: A) 5 sets of 5 RM on the leg press followed by a 5km run performed continuously (average velocity of the first and second ventilatory thresholds, $v\Delta 50$), B) 5 sets of 5 RM on the leg press followed by a 5km run performed intermittently (1 min run at the vVO_2max : 1 min of rest); C) 2 sets of 15 RM on the leg press followed by a 5km continuous run; and D) 2 sets of 15 RM on the leg press followed by a 5km intermittent run. Heart rate, blood lactate concentration, rate of perceived exertion, and VO_2 at the first and the fifth km were considered for statistical purposes. There were no significant effects of both strength bouts on any of the variables associated with endurance performance ($p > 0.05$). It seems that both maximum and strength endurance bouts do not acutely impair aerobic performance.

Key words: Running, concurrent training, interference effect, ratings of perceived exertion, oxygen consumption.

Introduction

Physical activity enthusiasts and athletes often perform strength and aerobic exercises in the same training session and/or training period in an attempt to improve their health status and fitness level. The combination of these exercises is known as concurrent training (CT). Classically, CT interferes in muscle strength improvements (Bell et al., 2000; Hickson, 1980). However, some authors have also suggested that CT may impair VO_2max gains (Nelson et al., 1990) and aerobic performance (Chtara et al., 2005). Docherty and Sporer (2000) and others have characterized these impairments in training adaptations and performance as the interference phenomenon (Docherty and Sporer, 2000; Kraemer et al., 1995).

One hypothesis to explain the interference phenomenon is the residual fatigue produced by the exercise mode performed first in the training session (Leveritt et al., 1999). Docherty and Sporer (2000) hypothesized that when both aerobic and strength training stimuli rely on peripheral mechanisms, acute interference should occur. For instance, if a previous aerobic exercise was performed at a high enough intensity to deplete muscle glycogen stores, a subsequent strength endurance bout would be negatively affected. On the other hand, maximum strength exercise, which seems to be highly dependent on neural drive, should not be affected by a previously performed aerobic exercise bout. Accordingly, our prior research demonstrated that a high intensity intermittent aerobic exercise bout interfered in a subsequent strength endurance exercise bout ($p = 0.03$) (de Souza et al., 2007). However, we also found that this aerobic exercise bout produced a trend towards impairments on a maximum strength bout ($p = 0.07$) (de Souza et al., 2007), which was not predicted by Docherty and Sporer's (2000) model. Thus, an alternative way to test the appropriateness of the peripheral fatigue hypothesis is reversing the order of the exercise bouts within a session (i.e. strength or strength endurance bout performed before the continuous or intermittent aerobic bout).

Nevertheless, only a limited number of studies have investigated the acute effects of a previous strength exercise bout on the physiological responses to aerobic exercise (Bailey et al., 1996; Drummond et al., 2005). Drummond et al. (2005) reported higher oxygen consumption (VO_2), heart rate (HR), and rate of perceived exertion (RPE) when continuous aerobic running (70% of the VO_2max) was preceded by seven strength exercises (i.e. 3 sets of 10 repetitions at 70% of the exercise 1 RM) designed to stress all major muscle groups.

There are three major drawbacks to Drummond's study. First, is that the whole body strength exercise routine increased overall resting energy expenditure which would naturally change and bias VO_2 and RPE readings during the aerobic exercise. Second, only the effects of a strength endurance bout on aerobic exercise were investigated. Finally, it was not possible to test if the interference on aerobic performance is independent of the aerobic exercise mode, since only continuous aerobic exercises were tested after the strength exercises.

An attractive way to test this acute interference effect would be using the same muscle groups for both the strength (endurance and maximum) and aerobic (moderate-continuous and intense intermittent) bouts. Thus, the aim of this study was to investigate if there were acute interference effects of maximum strength and strength endurance exercises on aerobic performance related variables such as VO_2, RPE, HR and blood lactate concentration during a subsequent 5-Km run that was performed in a continuous or intermittent fashion at moderate and high intensities, respectively. Based on our previous results (de Souza et al., 2007), the hypothesis of the present study was that strength endurance bout should affect the physiological variables associated with both aerobic exercise modes.

Received: 01 April 2011 / Accepted: 28 July 2011 / Published (online): 01 September 2011

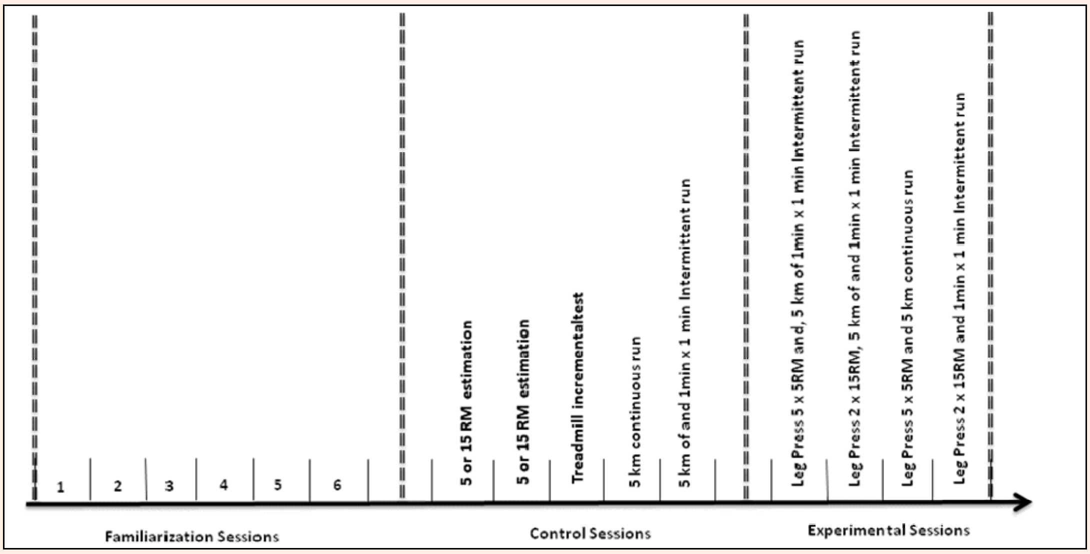

Figure 1. **The experimental design.**

Methods

This was a crossover study in which subjects performed five control sessions and four experimental sessions. The purposes of the control sessions were to estimate the exercise loads to perform the five sets of five maximal repetitions (5x5RM) and two sets of fifteen maximal repetitions (2x15 RM) in the inclined leg press (45°), to determine the VO_2max velocity ($v$$VO_2$max), and the first ($v$LT1) and the second ($v$LT2) lactate thresholds during a maximal incremental treadmill test. On each experimental session, participants had to perform a strength exercise bout before an aerobic exercise bout, as follows: experimental session A) 5 sets of 5 RM on the leg press with a 3-min rest between the sets followed by a 5km run performed continuously (at the average velocity of the first and second ventilatory thresholds, $v\Delta50$); B) 5 sets of 5 RM on the leg press with a 3-min rest between the sets followed by a 5km run performed intermittently (1 min run at the $v$$VO_2$max :1 min of rest); C) 2 sets of 15 RM on the leg press with a 3-min rest between the sets followed by a 5km continuous run; and D) 2 sets of 15 RM on the leg press with a 3-min rest between the sets followed by a 5km intermittent run. The order of the experimental sessions was balanced and randomized using the William's square technique (Kuehl, 2000). Figure 1 gives a pictorial view of the experimental design.

Participants

Eleven physically active males volunteered for this study (Table 1). All participants had at least one year of aerobic and resistance training experience and were performing both training modes at least twice a week. Participants were classified as category three (High) in accordance with the International Physical Activity Questionnaire (IPAQ). They performed vigorous-intensity activities on at least three days and accumulating at least 1,500 met·min^{-1}·week^{-1} or seven or more days of any combination of walking, moderate-intensity or vigorous intensity activities achieving a minimum of at least 3,000 met·min^{-1}·week^{-1}. In addition, the participants were fully adapted to the strength and aerobic exercises employed here (VO_2max averaged 58.2 ± 8.2 ml·min^{-1}·kg^{-1} and 5RM and 15RM loads were 310.6 ± 19.9 and 258.0 ± 14.6 kg, respectively). The study was approved by the Institution's Ethics Committee and all subjects were informed of the inherent risks and benefits before signing an informed consent form.

Table 1. **Mean (±SD) descriptive characteristics of the sample.**

Age (yrs)	23.1(3.1)
Height (m)	1.75 (.07)
Weight (Kg)	70.5 (8.8)
VO_{2max} (ml·min^{-1}·Kg^{-1})	58.2 (8.3)
vVO_{2max} (Km·h^{-1})	16.7 (1.6)
vLT1 (Km·h^{-1})	10.9 (1.5)
vLT2 (Km·h^{-1})	14.3 (1.2)
vΔ50 (Km·h^{-1})	12.6 (1.3)

VO_{2max} = maximum oxygen uptake; vVO_{2max} = minimum velocity to achieve VO_{2max}; vLL1 = aerobic threshold velocity; vLL2 = anaerobic threshold velocity; vΔ50= average velocity (vLL1+vLL2/2).

Familiarization sessions

Participants went through six familiarization sessions, performed at least four days apart, to get acquainted to the strength and the aerobic exercises, and to determine the 5RM and the 15RM loads. To avoid any residual effect, the participants were instructed to refrain from exercise 2 days before the experimental sessions. During a standard warm up subjects ran for 5 min at 9 km·h^{-1} on the treadmill (Sper ATL, Inbrasport®, Porto Alegre, Brazil) followed by 2 sets of 5 repetitions on the 45° inclined leg press (Nakagym®, São Paulo, Brazil) with 50 and 70% of four times their body mass, in the first and in the second sets, respectively. In the first and in the second familiarization sessions the participants performed four leg press sets to get an initial estimation of the 5RM and the 15RM loads, and intermittent running bouts on the treadmill. In the third and fourth familiarization sessions, a more precise estimate of the 5RM and the 15RM loads were obtained. The subjects performed up to 3 sets of 5 repetitions and 2 sets of 15 repetitions to obtain their maximum load for each repetition range. A 3-min interval was allowed between sets for both loads. Finally, the 5RM load (310.6 ± 19.9 kg) was obtained in the fifth familiarization session and the 15RM load (258.0 ± 14.6 kg) on the sixth session using the estimates obtained in the previous sessions.

Control sessions

The first and the second control sessions were used to determine and to match the total work load (repetitions x sets x load) for the 5 sets of 5RM and for the 2 sets of 15RM in the leg press. There was a 3-min interval between sets for both exercise loads.

In the third control session the participants performed a maximal treadmill incremental test (Sper ATL, Inbrasport®, Porto Alegre, Brazil). Before each test, the gas analyzer was calibrated using ambient air and a gas of a known composition (20.9% O_2 and 5% CO_2). The turbine flowmeter was calibrated using a 3-L syringe (Quinton Instruments, Seattle, WA, USA). The heart rate (HR) was monitored during the test with a heart rate transmitter (model S810, Polar Electro Oy, Kempele, Finland) coupled with the gas analyzer (Quarkb2, Cosmed®, Rome, Italy). The test started at 6 $km \cdot h^{-1}$ with increments of 1.2 $km \cdot h^{-1}$ every 3-min, until exhaustion (Heck et al., 1985). Throughout the test, the subjects wore a mask (Hans Rudolph®, Kansas City, MO, USA) connected to the gas analyzer for breath-by-breath measurements of gaseous exchange. The data was smoothed averaging the data over 10-sec intervals and maximum oxygen uptake (VO_2max) was obtained from the average of the three highest values at the last stage (Weston et al., 2002). Verbal encouragement was provided to ensure that maximal values were reached. At the end of each 3-min stage, 25 µl of arterialized blood were drawn from the ear lobe to measure the blood lactate concentration [La-] (Yellow Springs 1500 Sport, Yellow Springs®, USA). The first and second lactate thresholds (*v*LT1 and *v*LT2), expressed in km•h-1, were determined mathematically after visual identification of the two intersection points by three evaluators (Ribeiro et al., 1986). In addition, the rated perceived exertion (RPE) was measured at the end of each stage according to the Borg scale (from 6 to 20). Tests were performed at the same time of the day, room temperature (20-24°C) and at least 2 h after the last meal.

In the fourth and fifth control sessions, participants ran 5Km continuously at the *v*Δ50 or intermittently (1:1 min) performed at the velocity associated with the VO_{2max} (vVO_2max), respectively. HR and VO_2 were monitored continuously from beginning to the end of exercise period by the heart rate transmitter and gas analyzer, respectively. VO_2 data were smoothed by 10-sec averages and the values of the last 1-min of total exercise in the continuous exercise and last 30-sec of each 1-min interval in intermittent exercise were analyzed. RPE and [La-] were assessed before, after every 1km interval and immediately after the completion of the 5Km run.

Experimental sessions

On experimental sessions A and B after performing 5 sets of 5RM in the leg press participants ran either 5km continuously (Session A) at the *v*Δ50 or intermittently (Session B) at the vVO_{2max}. Sessions C and D consisted of 2 sets of 15RM in the leg press followed by either a 5km continuous run (Session C) at the *v*Δ50 or a 5km run performed intermittently (Session D) at the vVO_{2max}.

Statistical analysis

Data homogeneity and normality were confirmed by standard visual and quantitative (Shapiro-Wilk) methods. The comparison of the total leg press work load between the experimental sessions was performed through a mixed model having pre-aerobic exercise protocol *(i.e.,* control, maximum strength and strength endurance) and aerobic exercise protocol (*i.e.,* continuous and intermittent) as fixed factors and subjects as a random factor (Ugrinowitsch et al., 2004). Heart rate, blood lactate concentration, RPE, and VO_2 differences between experimental sessions were compared at the end of the first and the fifth kilometres using mixed models having pre-aerobic exercise protocol (*i.e.,* control, maximum strength, and strength endurance) and aerobic exercise protocol (i.e., continuous and intermittent) as fixed factors, and subjects as random factors (Ugrinowitsch et al., 2004). Whenever a significant F-value was obtained, a post-hoc test with a Tukey adjustment was performed for multiple comparison purposes. Significance level was set at $p \leq 0.05$.

Results

There were no differences for total work done (kg) in both maximum strength and strength endurance experimental interventions (i.e. control, continuous and intermittent aerobic exercises) (Table 2).

Table 2. Mean(±SD) leg-press total lifted load (Kg) in the maximum strength and strength endurance sessions before the control, continuous and intermittent aerobic exercises.

	Maximum Strengt	Strength Endurance
Control	7789 (498)	7739 (439)
Continuous	7827 (452)	7812 (405)
Intermittent	7818 (443)	7796 (404)

There was a significant increase in HR during the intermittent aerobic exercise sessions (main aerobic exercise effect, p = 0.038) at the first kilometer (166 ± 14, 168 ± 14 and 168 ± 15 $b \cdot min^{-1}$ for the control-intermittent, maximum strength-intermittent and intermittent-strength endurance-intermittent conditions, respectively). However, this HR effect was not observed at the end of the fifth kilometer (176 ± 16, 173 ± 17 and 176 ± 15 $b \cdot min^{-1}$ for the control-intermittent, maximum strength-intermittent and strength endurance-intermittent conditions, respectively).

There were no differences in HR for the control-continuous, maximum strength-continuous and strength endurance-continuous conditions at the first kilometer (158 ± 13, 163 ± 17, and 162 ± 21 $b \cdot min^{-1}$, respectively) and at the fifth kilometer (171 ± 20, 175 ± 23 and 173 ± 24 $b \cdot min^{-1}$, respectively).

The [La-] was significantly higher ($p < 0.05$) at the start of both aerobic exercise modes when preceded by the maximum strength and strength endurance exercises (data not shown). However, there were no differences in [La-] between exercise sessions at the first kilometer for the control-continuous, maximum strength-continuous, and strength endurance-continuous conditions (2.7 ± 0.8, 2.7 ± 1.2, and 3.2 ± 1.8 $mmol \cdot L^{-1}$, respectively) and for the control-intermittent, maximum strength-intermittent, and strength endurance-intermittent (3.7 ± 2.3, 2.8 ± 1.5, and 3.1 ± 1.1 $mmol \cdot L^{-1}$, respectively).

There was also significantly higher [La-] (main aerobic exercise effect $p = 0.049$) at the fifth kilometer of the intermittent exercise than of the continuous exercise conditions (control-intermittent - 4.5 ± 1.7 vs control-continuous - 2.4 ± 1.0, maximum strength-intermittent - 3.3 ± 1.3 vs maximum strength-continuous - 2.7 ± 1.7, and strength endurance-intermittent - 3.0 ± 1.1 $mmol \cdot L^{-1}$ vs strength endurance-continuous - 2.6 ± 1.5 $mmol \cdot L^{-1}$).

Overall there was trend toward greater RPE values for the intermittent than for the continuous exercise sessions at the first (11.9 ± 2.3 and 10.9 ± 1.8 a.u., respectively) and at the fifth kilometer (18.30 ± 2.0 and 16.9±3.1 a.u., respectively) (aerobic exercise effect, $p = 0.072$ and $p = 0.071$, respectively).

There were no differences in VO_2 between continuous and intermittent aerobic exercises after the experimental interventions ($p > 0.05$). VO_2 values at the fifth kilometer were similar between the continuous and intermittent exercise sessions (i.e. 45.0 ± 5.2, 44.9 ± 5.2, and 46.6 ± 6.1 $ml \cdot kg^{-1} \cdot min^{-1}$ for the control-continuous, maximum strength-continuous, and strength endurance-continuous and 47.7 ± 9.6, 46.3 ± 7.5, and 47.1 ± 6.9 $ml \cdot kg^{-1} \cdot min^{-1}$ for the control-intermittent, maximum strength-intermittent, and strength endurance-intermittent).

Discussion

The purpose of this study was to examine the effects of a previous strength endurance or maximal strength exercise bout on the responses of physiological variables during continuous and intermittent aerobic exercises. The main finding of the current study was that neither the maximum strength nor strength endurance exercise bouts produced acute changes in La-, VO_2, HR and RPE during a continuous or an intermittent aerobic exercise. These results do not support the hypothesis that strength endurance should produce interference on variables associated with continuous or intermittent aerobic exercise.

Few studies have investigated the acute effects produced by strength exercises on physiological aerobic variables (Bailey et al., 1996; Drummond et al., 2005). In contrast to our findings, Drummond et al. (2005) found that a strength endurance bout resulted in 5%, 15%, and 5% increases in HR, RPE, and VO_2, respectively during a continuous aerobic bout. It is plausible that the differences seen between studies are an artifact of the differences in the design of our strength exercise protocols. Specifically, we used two (2x15 RM) and five sets (5x5 RM) of the leg press exercise for the strength endurance and maximum strength exercise bout, respectively, while Drummond et al. (2005) used 3 lower limb, and 4 upper body exercises performed for 3 sets of 10 repetitions for each exercise (70% 1-RM). There are two possible explanations for the divergent findings between the present study and Drummond's work. Firstly, Drummond et al. (2005) imposed a higher overload to the lower limb muscles than in the present study due to the greater total volume performed by these muscle groups. Thus, it is conceivable that participants of their study had a greater degree of peripheral fatigue in the lower limb muscles at the start of the aerobic exercise than our participants. Secondly, the whole body workout performed in the referred study may have produced some degree of central fatigue impairing the performance during the subsequent aerobic activity, while the single exercise workout used in our study may have prevented the occurrence of this type of fatigue.

The current study does not support the hypothesis that some training protocols would minimize or maximize the interference effect. The theoretical model previously presented suggests that regardless exercise order, the interference effect would occur when both stimuli (strength and endurance) were designed to deplete the energy stores of the skeletal muscles (Docherty and Sporer, 2000). Previous work from our group (de Souza et al., 2007) found that performing an intermittent aerobic exercise session prior to a strength exercise resulted in impairments in strength-endurance performance ($p = 0.03$) and a trend ($p = 0.07$) to decrease maximum strength. However, the lack of change in the aerobic variables reported in the present study does not support the notion that a strength-endurance exercise impairs variables underlying aerobic performance. Taken together, our data suggest that the interference effect occurs only when the aerobic exercise is performed first in the exercise session (Abernethy, 1993; Bentley et al., 2000; Sporer and Wenger, 2003).

In summary, the results of our present and past research do not appear to provide empirical support for the hypothesis that the acute interference phenomenon would occur when both exercise bouts (i.e. strength and aerobic) stress peripheral mechanisms and when a resistance training bout is performed prior to an aerobic bout.

Conclusion

Concurrent training has been widely used by athletes and physical activity enthusiasts. However, the sequence of training modalities (aerobic or strength) within a training session may produce the interference phenomenon. Our findings suggest that performing either maximum strength or strength endurance low volume exercises before aerobic exercises does not impair endurance performance.

Acknowledgments

The present study was funded by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) (2007/00922-4 for LFCR and 2007/02738-6 for EOS). The authors declare no conflict of interests.

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Key points

- Residual acute peripheral fatigue does not seem to be the only cause in the interference effect observed during concurrent training regimens.
- Peripheral fatigue mechanisms of running such as lactate concentration are not altered by prior lower volume strength exercises.
- Strength and strength endurance exercises performed before a running bout do not seem to impair the performance in the latter.

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