ACUTE EFFECT OF TWO AEROBIC EXERCISE MODES ON MAXIMUM STRENGTH AND STRENGTH ENDURANCE

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ABSTRACT. de Souza, E.O., V. Tricoli, E. Franchini, A.C. Paulo, M. Regazzini, and C. Ugrinowitsch. Acute effect of two aerobic exercise modes on maximum strength and strength endurance. J. Strength Cond. Res. 21(4):1286-1290. 2007.—The purpose of this study was to evaluate the effects of 2 modes of aerobic exercise (continuous or intermittent) on maximum strength (1 repetition maximum, IRM) and strength endurance (maximum repetitions at 80% of 1RM) for lower- and upper-body exercises to test the acute hypothesis in concurrent training (CT) interference. Eight physically active men (age: 26.9 ± 4.2 years; body mass: 82.1 ± 7.5 kg; height: 178.9 ± 6.0 cm) were submitted to: (a) a graded exercise test to determine \( \text{VO}_\text{max} \) (39.26 ± 6.95 ml·kg\(^{-1}\)·min\(^{-1}\)) and anaerobic threshold velocity (3.5 mmol·L\(^{-1}\)·h\(^{-1}\)); (b) strength tests in a rested state (control); and (c) 4 experimental sessions, at least 7 days apart. The experimental sessions consisted of a 5-kilometer run on a treadmill continuously (90% of the anaerobic threshold velocity) or intermittently (1:1 minute at \( \text{VO}_\text{max} \)). Ten minutes after the aerobic exercise, either a maximum strength or a strength endurance test was performed (leg press and bench press exercises). The order of aerobic and strength exercises followed a William’s square distribution to avoid carryover effects. Results showed that only the intermittent aerobic exercise produced an acute interference effect on leg strength endurance. Decreasing significantly \( p < 0.05 \) the number of repetitions from 10.8 ± 2.5 to 8.1 ± 2.2. Maximum strength was not affected by the aerobic exercise mode. In conclusion, the acute interference hypothesis in concurrent training seems to occur when both aerobic and strength exercises produce significant peripheral fatigue in the same muscle group.

KEY WORDS. concurrent training, fatigue

INTRODUCTION

Any sport requires simultaneous expression of strength and endurance abilities. Due to this fact, athletes incorporate strength and endurance exercises into their training routines. However, training both strength and endurance may produce interference effects, reducing the magnitude of training adaptations and performance increments (2, 3, 7, 8, 15). Several studies have indicated decreased strength gains with this type of training (6, 7, 9), which is usually called concurrent training (CT). These studies have suggested 3 hypotheses to explain the strength development impairment: (a) the chronic hypothesis, which states that some adaptations caused by endurance training are antagonist to strength training adaptations (10); (b) the overtraining hypothesis, which suggests that concomitant volume increments in both endurance and strength training loads may cause overtraining syndrome (10); and (c) the acute hypothesis in which an endurance training, performed prior to a strength training in the same training session, would produce residual fatigue, compromising force production during the strength training session (9).

Craig et al. (6) were the first to propose an acute interference effect to explain the CT phenomenon. They stated that there is an acute fatigue effect from a previous endurance exercise on strength exercise performance (1, 6). The acute peripheral fatigue from the endurance exercise would then reduce the ability of skeletal muscles to produce tension (4). Some authors have suggested that the degree of muscle tension is critical for strength gains. Thus, any exercise that decreases the ability of the muscles to produce tension will lead to submaximal strength development (1, 6, 9).

Particularly, the studies that tested the acute hypothesis produced controversial results (1, 6, 9, 11). Sporer and Wenger (17) observed a significant strength endurance decrement after 36 minutes of continuous cycling at 70% of the maximum aerobic power, while Leveritt et al. (11) found no significant reduction in force production after a 50-minute exercise in a cycloergometer at 70–110% of the critical power.

In a review paper, Docherty and Sporer (7) proposed that this acute interference phenomenon is present only when aerobic and strength exercises are both dependent on peripheral or central mechanisms. Thus, if the intensity of an aerobic exercise is high enough to deplete muscle glycogen content, then strength endurance performance will be greatly affected. On the other hand, maximum strength will not be significantly affected because it relies more in the neural drive for force production than in the muscle fiber force generation capacity and glycogen store. Thus, it is not known if the combination of endurance and strength exercises in a training session, stressing either central or peripheral mechanisms, produces greater interference effects than a session in which this combination alternates stress over peripheral and central mechanisms.

Another explanation to interference may be the motor unit pool activated during both exercises. Small motor units are predominantly recruited in low force contractions. As the force level increases, larger motor units composed of fast twitch fibers are also recruited (size principle). Low-intensity aerobic training should then recruit only slow motor units due to the low force requirement. On the other hand, high-intensity aerobic training (>90% \( \text{VO}_\text{max} \)) should activate both small and large motor units. In the same way, low-intensity strength workout activates mainly small motor units, while strength training above 70% of 1 repetition maximum (1RM) requires...
the activation of both small and large motor units. Thus, Nelson et al. (12) proposed that strength training and endurance training could activate the same motor unit pool and then maximize the acute interference phenomenon.

The aim of this study was to evaluate if the hypothesis developed by Docherty and Sporer (7) for CI interference effect is valid when both aerobic and strength exercises stress peripheral mechanisms, in a practical context.

**METHODS**

**Experimental Approach to the Problem**

This study was designed to investigate if CI interference is caused only when both aerobic and strength exercises stress peripheral mechanisms, as proposed by Docherty and Sporer (7). Thus, we tested the effects of 2 modes of aerobic exercise, continuous (below anaerobic threshold), which should stress central mechanisms, and intermittent (1:1 minute at VO\textsubscript{max}) to stress peripheral mechanisms, on maximum strength (central) and strength endurance (peripheral) for lower- and upper-body exercises.

**Subjects**

Eight physically active male subjects were selected to participate in this study. Their mean (± SD) age, body mass, height, VO\textsubscript{max}, and anaerobic threshold velocity (3.5 mmol-L\textsuperscript{-1}) were 26.9 (± 4.2) years, 82.1 (± 7.5) kg, 178.9 (± 6.0) cm, 39.26 (± 6.95) ml-kg\textsuperscript{-1} min\textsuperscript{-1}, and 9.3 (± 1.3) km-h\textsuperscript{-1}, respectively. They had 4.1 years of resistance training experience on average and exercised 1–3 times per week with loads 50–80% of 1RM. In addition, subjects had on average 4.2 years of participation in sports at a recreational level, 1–3 times per week. Subjects were screened for cardiovascular disorders through Par-Q and electrocardiographic records during the VO\textsubscript{max} test. The study was approved by the University’s ethic committee, and all subjects signed an informed consent form before participation.

**Experimental Design**

The study consisted of a randomized crossover design, in which all subjects completed both control and experimental conditions. Each session was 1 week apart to avoid any carryover effect (Figure 1).

**Familiarization Session**

The anaerobic threshold and VO\textsubscript{max} were assessed on this session. Subjects performed a progressive running speed test until voluntary exhaustion on a treadmill. Each stage lasted 3 minutes. The initial speed was set at 6.0 km-h\textsuperscript{-1}, and was increased 1 km-h\textsuperscript{-1} per stage until the subject could no longer continue. The O\textsubscript{2} uptake was measured throughout the test and the average of 3 largest values was defined as VO\textsubscript{max} (K4b\textsuperscript{2} Cosmed, Rome, Italy). The maximal velocity reached in the test, was defined as VO\textsubscript{max}. At the end of each stage, a 25 μl blood sample from the left ear lobe was collected in heparinized capillary tubes and stored in Eppendorfs. Blood lactate concentration was measured by electrochemical technique (Yellow Springs 1500 Sport, Yellow Springs, OH) after sodium fluoride stabilization (4.7 mM). One mmol above resting values and 3.5 mmol lactate concentrations were interpoltated from the raw data to estimate lactate and anaerobic threshold velocities, respectively. Subjects informed their rates of perceived effort (RPE) at the end of each stage. In addition, heart rate was monitored using a heart rate monitor (Polar Vantage NV, Electro Oy, Finland). After the VO\textsubscript{max} test, subjects were familiarized with the strength tests in the inclined (45°) leg press and in the bench press, and a gross estimate of the subject’s 1RM was obtained. The body position of the subjects in both exercises was defined and recorded for next familiarization and experimental sessions as follows:

**Inclined Leg Press.** Subjects were seated in the machine and placed both feet on the plate in a self-selected position. The area of the plate was divided into 10 cm squares to help record the feet location. Then, the machine was unlocked and the plate was lowered (or lifted) until a knee angle of 90° was obtained. Then, the position of the plate was defined in a measuring tape placed on the side of the sliding track. A plastic device was inserted in a 90° angle with the track to ensure correct position during each exercise repetition. The repetition started at complete knee extension; the subject lowered the plate until the specified height on the track, and then returned to full extension.

**Bench Press.** Subjects lay on the bench in a supine position with the shoulders under the bar and both feet on the ground. Then, subjects gripped the bar in a comfortable position. The distance of both thumbs from the center of the bar was recorded in a measuring tape placed over the bar. The repetition started in full elbow extension, the bar was lowered up to touching the chest, and the repetition finished returning to full extension.

**Control Sessions**

In the first control session the 1RM values for both exercises were determined, first for the inclined leg press and then for the bench press. The amount of weight used in the first repetition was defined as 80% of the weight lifted in the first familiarization session for each exercise. Then, subjects had up to 5 trials to reach maximum load with a 3-minute interval between trials. There was a 5-minute interval between exercises.

In the second control session subjects performed the strength endurance test. They had to perform as many repetitions as possible with a load of 80% of the 1RM in both exercises.

**Experimental Sessions**

Subjects performed 4 experimental sessions consisting of a 5-kilometer run on a treadmill continuously (CONT) (90% of the anaerobic threshold velocity, 8.1 ± 1.1 km-h\textsuperscript{-1}) or intermittently (INT) (1:1 minute at VO\textsubscript{max}, 12.6 ± 1.5 km-h\textsuperscript{-1}). Ten minutes after the aerobic exercise either a maximum strength (1RM) or a strength endurance test was performed (leg press and bench press exercises). Thus, the 4 experimental sessions were: continuous run and maximum strength (CM), continuous run and strength endurance (CE), intermittent run and maximum strength (IM), and intermittent run and strength...
endurance (IE). The experimental sessions were at least 7 days apart. The order of the experimental sessions followed a William’s square distribution to avoid carryover effects.

Statistical Analyses
A mixed model was performed having aerobic exercise modality (control, continuous, and intermittent) as a fixed factor and subjects as a random factor, for both response variables, maximum strength and strength endurance, for each exercise. 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 $p < 0.05$.

RESULTS
The continuous protocol produced no interference effect in either maximal strength or strength endurance for both leg press and bench press exercises (Figures 2, 3, and 4). On the other hand, the intermittent run produced a significant reduction only in leg press strength endurance (from 10.8 ± 2.5 to 8.1 ± 2.2 repetitions, $p = 0.03$) (Figure 5), but there was also a trend to decrease lower limb maximum strength ($p = 0.07$).

DISCUSSION
The purpose of this study was to evaluate the acute effect of 2 aerobic exercise modes, CONT and INT, on maximum strength and strength endurance on both the lower and upper body. The main finding of this study was that the INT reduced significantly lower-body strength endurance and nonsignificantly maximum strength.

The CONT aerobic exercise (90% anaerobic threshold velocity) affected neither maximal strength nor strength endurance, which is in disagreement with some previous studies. Abernethy (1) had a group that performed continuous aerobic exercise for 150 minutes at 35% of peak cycle ergometer oxygen consumption and found a small, but significant (4%) decrement in knee extension peak torque. Sporer and Wenger (17) also observed a significant strength endurance decrement after 36 minutes of continuous cycling at 70% of the maximum aerobic power. On the other hand, Leveritt et al. (11) found that strength...
was not reduced after aerobic exercise in a cycle ergometer (50 minutes at 70–110% of the critical power). The difference between our results and the results of the studies that found interference may be attributed to the aerobic exercise performed in a cycle ergometer, which is believed to produce a greater stress upon the lower limb muscles than a running exercise. In addition, the study that did not find interference of the aerobic bike protocol only evaluated strength 8 hours after exercise completion (12). This time window may be large enough to produce full strength recovery. Thus, the interference produced by low-intensity aerobic exercise seems to occur when it requires greater force production than in running.

The INT produced a significant reduction in lower-body strength endurance ($p = 0.03$). The mean number of repetitions after INT protocol decreased significantly from 10.8 ± 2.5 to 8.1 ± 2.2. Sporer and Wenger (18) also found that the number of repetitions performed over 4 sets in the leg press decreased significantly (48 ± 3 SE vs. 36 ± 3 SE), 4 hours after intermittent aerobic exercise. Leveritt and Abernethy (11) reported a reduction in the number of repetitions in the squat exercise in the first set when performed 30 minutes after intermittent aerobic protocol (13.83 ± 5.71 vs. 8.83 ± 2.89). All these results support the acute hypothesis proposed by Craig et al. (6).

In addition, Docherty and Sporer (7) proposed that the acute interference phenomenon occurs only when high-intensity intermittent aerobic training (>90% $V_o^{max}$) is performed concurrently with resistance training of 8 to 12RM. Sale (14) described that fast motor units are activated in running activities performed close to $V_o^{max}$. During strength endurance exercise we should expect that not all motor units are recruited. However, fast motor units have a low resistance to fatigue and are not able to keep activated for a long period of time. Then, fresh fast motor units have to be recruited to keep force production. This phenomenon is defined as motor unit substitution (19). Therefore, it is expected that the majority of the available motor units are recruited during strength endurance exercise, which have also been activated during the intermittent aerobic exercise.

Probably, not only motor unit recruitment but other factors such as accumulation of metabolites could explain the acute interference phenomenon during concurrent training. When a high-intensity aerobic exercise is performed, part of the energy requirement is produced by glycolysis, which has metabolic end products (lactate, $H^+$, ADP/AMP, $P_i$). Such metabolites are thought to impair energy production and hence force generation (5, 13, 18). Moreover, exercise characteristics may influence production of metabolites. Smilios et al. (16) described higher blood lactate accumulation after strength endurance than maximum strength exercise.

In our study, the decrease in maximal strength almost reached significance ($p = 0.07$) after INT. This finding demonstrates that the INT had the potential to decrease maximal strength. Bentley et al. (4) showed that maximal isometric force of the quadriceps was decreased 6 hours after exhausting intermittent aerobic exercise. In order to produce a maximum strength repetition (1RM) all available motor units have to be recruited, but they will be fatigued from the previous aerobic exercise. Thus, we could also expect a decreased maximum strength performance. A greater sample size may have produced a significant decrement in force production. Taking the trend towards a decreased maximum strength and the theory behind motor unit activation together, we may say that our data do not corroborate the hypothesis proposed by Docherty and Sporer (7).

The other finding was that aerobic exercise affected only the muscles involved in this activity. Neither upper-body maximal strength nor strength endurance was affected by the CONT or the INT aerobic exercise. Only 1 study examined the acute effect of an aerobic exercise in the ability to exert force in a muscle group not exercised during this activity. Sporer and Wenger (17) found that the average repetitions over 4 sets of a strength exercise were not affected by either continuous or intermittent aerobic exercise. These data demonstrated that the interference effect is caused mainly by peripheral factors (peripheral fatigue). Thus, we may say that aerobic training does not affect strength in the muscles not exercised during aerobic activity.

In conclusion, our study demonstrated that only INT decreased the number of repetitions in strength endurance and presented a potential to produce interference in maximal strength in the muscles involved in both tasks. The CONT protocol interfered in neither maximal strength nor strength endurance.

**Practical Applications**

Our results indicate that both maximum strength and strength endurance may be trained after a continuous low-intensity and moderate duration aerobic exercise, since there is no acute interference effect. On the other hand, if the main goal of the training session is to develop either maximum strength or strength endurance, they should be performed before an intermittent aerobic exercise at $V_o^{max}$. This aerobic exercise may produce fatigue and impair strength development.

**References**


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