ACUTE EFFECT OF HIGH-INTENSITY AEROBIC EXERCISE PERFORMED ON TREADMILL AND CYCLE ERGOMETER ON STRENGTH PERFORMANCE

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ABSTRACT
Panissa VLG, Tricoli VAA, Julio UF, Ribeiro N, de Azevedo Neto RM, Carmo EC, and Franchini E. Acute effect of high-intensity aerobic exercise performed on treadmill and cycle ergometer on strength performance. J Strength Cond Res 29(4): 1077–1082, 2015—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. Thus, this study aimed to verify the acute effects of previous running and cycling on strength endurance performance. After the determination of the maximum intensity reached (I_{max}) during treadmill running and cycle ergometer pedaling and half-squat maximum strength (1 repetition maximum [1RM]), 10 physically active men were submitted to 3 experimental conditions: control condition (S) comprised of 4 sets of maximum repetitions at 80% 1RM, intermittent running (RS), and cycling (CS) conditions (15 × 1 minute:1 minute in the I_{max}) followed by the strength exercise (S). Maximum number of repetitions (MNR), total session volume (TV), and vastus lateralis electromyographic signal (VL_{EMG}) were analyzed. It was observed that MNR and TV performed in set 1 in the S condition was superior to that performed in set 1 in the RS (p < 0.001) and CS (p < 0.001) conditions; and set 2 in the S condition was superior to set 2 only in the CS for the MNR (p = 0.032) and TV (p = 0.012). For the VL_{EMG}, there was a main effect for repetition, with higher values in the last repetition compared with the second one (p < 0.01). In conclusion, an aerobic exercise bout before strength exercise impairs the subsequent strength endurance performance. In addition, the magnitude of the interference effect was higher after the aerobic cycling exercise.

KEY WORDS: concurrent training, electromyography, aerobic exercise mode

INTRODUCTION
Strength training is recommended to improve muscle force production capacity and to increase muscle mass. However, endurance training induces better oxygen transport and utilization (20). Both strength and endurance training have been incorporated simultaneously into training routines in many sports (27) and physical activities (12). This combination is defined as concurrent training.

Concurrent training may decrease acute strength performance (3,9,10,21,33) and impairment long-term strength development (2,16,17,20). The causes of this impairment in strength development are not well established. However, some studies have reported that an acute effect may be partially responsible for this phenomenon (8,21,28). The acute interference hypothesis suggests that there is a reduction in performance (i.e., maximum number of repetitions [MNR] or total volume [TV]) during the strength training session when an aerobic activity is executed before the strength exercise bout. This reduction produced in each session may decrease training stimuli when compared with strength training alone. Thus, the acute interference may contribute to the long-term impairment in strength gains after a period of concurrent training.

The acute interference magnitude may be dependent on several variables such as rest interval length between endurance and strength exercises (25,33), muscle group involved in both exercises (9,21–23,33), and exercise intensity (9,10). Particularly, de Souza et al. (9) demonstrated that high-intensity intermittent exercise (i.e., near the V̇O_{2max}) led to a greater interference effect on a strength endurance exercise performed at 80% 1 repetition maximum (1RM).

Another important variable to be considered is the aerobic exercise mode. It has been shown that both running (9) and...
cycling (1,3,21,33) exercises cause negative effects on the subsequent strength performance. It seems that cycling has an elevated concentric contraction component (4), a high level of muscle glycogen depletion (19,30), and carbohydrate oxidation (19) when compared with running. Moreover, fatigue in concentric actions is more dependent on the neural factors than in eccentric actions (11,14,18). Considering that the concurrent activities would be affected by muscle activity pattern (3,5,26), the interference magnitude may be different when comparing cycling and running due to the predominance of a specific type of muscle action (concentric and eccentric) in each exercise (24).

However, to the best of our knowledge, there are no data in the literature comparing the effects of high-intensity aerobic intermittent exercise mode on acute strength performance. Therefore, the purpose of this study was to compare the effects of high-intensity running and cycling endurance exercises on acute strength performance and muscle activity pattern. Our hypothesis is that due to the elevated concentric action content during cycling, concurrent training using this aerobic exercise mode would generate more interference effects on strength performance when compared with concurrent training with running. A better understanding of how different modes of aerobic exercise affect subsequent strength performance may contribute to more ideal exercise prescriptions for athletes and physically active individuals.

METHODS

Experimental Approach to the Problem

This was a crossover study. To investigate whether the magnitude of concurrent training interference would be dependent on the characteristics of the endurance exercise mode, all participants were submitted to 6 experimental sessions. The effects of running or cycling on the MNR, TV, and vastus lateralis (VL) muscle activity were investigated during a concurrent training session. Maximal oxygen consumption (VO₂peak) and maximal intensity attained (Iₘₐₓ) were measured in both running and cycling tests. Maximum dynamic strength (1RM) in the half-squat exercise was assessed before the experimental sessions. The running and cycling exercises were performed intermittently and consisted of fifteen 1-minute bouts at an equalized intensity (Iₘₐₓ) separated by 1-minute passive rest interval. After that, individuals performed 4 series of half-squat exercise at 80% 1RM until concentric failure.

Subjects

Ten physically active male subjects aged between 18 and 35 years (24 ± 2 years, 176 ± 5 cm, 79.5 ± 6.7 kg; 1RM half-squat: 188.7 ± 27.8 kg; VO₂peak running: 45.03 ± 6.35 ml·kg⁻¹·min⁻¹, VO₂peak cycling: 32.55 ± 5.30 ml·kg⁻¹·min⁻¹, Iₘₐₓ running: 15.8 ± 1.6 km·h⁻¹, Iₘₐₓ cycling: 283.2 ± 41.8 W) participated in this study (women were excluded). They had at least 2 years of aerobic and strength training experience and participation in sports at a recreational level. Participants were free from health problems and neuromuscular disorders that could affect their ability to complete the study protocol. Furthermore, all of them were free of any drug or nutritional supplement ingestion during the period of the study. Possible cardiovascular disorders were evaluated by electrocardiographic records during the running and cycling VO₂peak test.

Participants took part voluntarily in the study after being informed of the procedures, risks, and benefits and signed an informed consent form. This study was approved by the University of São Paulo Ethics Committee, according to Brazilian Federal Law 196/96.

Procedures

Subjects completed 6 experimental sessions separated by at least 72 hours. During the first and second sessions, anthropometric, VO₂peak, and Iₘₐₓ measurements on treadmill and cycle ergometer were taken. Running and cycling peak oxygen consumption tests were performed in randomized order. After the maximal endurance cycling and running tests, participants were familiarized with the 1RM test procedures, and the test was conducted during the third experimental session.

The next 3 experimental sessions were also applied in randomized order: a control session in which participants performed only the half-squat strength exercise (S) (4 sets at 80% 1RM), a high-intensity intermittent running (RS) exercise session, and a high-intensity intermittent cycling (CS) exercise session. Both endurance exercise bouts were composed of 15 × 1 minute:1 minute at Iₘₐₓ and were followed by the strength exercise using the same protocol applied in the S condition. A 15-minute rest interval was granted between the endurance and the strength exercises. A minimum of 48-hour rest was observed between tests to avoid interference between different interventions. Testing took place at the same time of the day for each subject. The subjects were instructed to abstain from any strenuous exercise at least 48 hours before each testing session and were encouraged to maintain their nutritional and hydration routines.

Maximal Endurance Running Test

The subjects performed an incremental test to volitional exhaustion. The initial treadmill (Movement e-750, Movement, São Paulo, Brazil) speed was set at 8.0 km·h⁻¹, and it was increased by 1 km·h⁻¹ per 1-minute stage until the participant could no longer continue. The oxygen uptake was measured (k4b²; Cosmed, Rome, Italy) throughout the test, and the average of the last 30 seconds was defined as VO₂peak. Before each test, the O₂ and CO₂ analysis systems were calibrated using ambient air and a gas of known O₂ and CO₂ concentration (16 and 5%, respectively) according to the manufacturer’s instructions. The turbine flowmeter was calibrated using a 3-L syringe (Quinton Instruments, Seattle, WA, USA). The maximal velocity reached in the test was defined as the maximal intensity attained (Iₘₐₓ). When the
subject was not able to finish the 1-minute stage, the speed was expressed according to the permanence time in the last stage, determined as the following: \( I_{\text{max}} = \text{velocity of penultimate stage} \times (\text{time, in seconds, remained at the last stage} \times \text{multiplied by 1 km h}^{-1}/60 \text{ seconds}) \).

Maximal Endurance Cycling Test
The participants performed an incremental test to volitional exhaustion. The initial electromagnetic cycle ergometer (Ergo Fit 167, Ergo-Fit GmbH & Co, Pirmasens, Germany) load was set at 30 W, and it was increased by 25 W per 1-minute stage until the participant could no longer continue. The oxygen uptake was measured (k4b2; Cosmed) throughout the test, and the average of the last 30 seconds was defined as \( V_{\text{O2peak}} \). Calibration procedures were the same as in the running condition. The maximal load reached in the test was defined as the maximal intensity attained (\( I_{\text{max}} \)). When the subject was not able to finish the 1-minute stage, the power was expressed according to the permanence time in the last stage, determined as the following: \( I_{\text{max}} = \text{power of penultimate stage} \times (\text{time, in seconds, remained at the last stage} \times \text{multiplied by 25 W}/60 \text{ seconds}) \).

Maximum Dynamic Strength Test
Half-squat maximum dynamic strength (IRM) was assessed using a Smith machine (Cybex, Medway, MA, USA). The test was performed according to standard procedures (6). Briefly, the subjects began the test with a general warm-up, consisting of cycling (70 rpm at 50 W) for 5 minutes, followed by 2 specific warm-up sets. In the first set, the subjects performed 8 repetitions at 50% of the estimated 1RM, and for the second set, they performed 3 repetitions at 70% of the estimated 1RM with 2-minute interval between sets. After the specific warm-up, the subjects rested for 2 minutes and then had up to 5 trials to achieve the 1RM load (i.e., maximum weight that could be lifted once with proper technique), with 3- to 5-minute interval between trials.

For better control of the IRM test procedures, each participant had his body position and feet placement in the half-squat exercise recorded and reproduced throughout the study. In addition, a wooden seat with adjustable heights was placed behind the participant to keep the bar displacement and knee angle (approximately 90°) constant on each half-squat repetition.

**High-Intensity Intermittent Endurance Exercise**
Participants performed a warm-up at 50% \( I_{\text{max}} \) for 5 minutes, and after 2 minutes, they started the exercise bout. The endurance exercise consisted of \( 15 \times 1\)-minute repetitions at \( I_{\text{max}} \) separated by 1-minute passive recovery on a treadmill or cycle ergometer.

**Strength Endurance Exercise**
The subjects performed a specific warm-up consisting of 12 repetitions at 50% 1RM, followed by 4 sets of maximum repetitions at 80% 1RM in the half-squat exercise performed on a Smith machine. Each set was separated by 2-minute rest interval. The MNR performed was recorded, and the TV was calculated (repetitions \times weight lifted).

**Electromyography Analysis**
Electromyographic (EMG) activity (EMG 521C; EMG System of Brazil, São José dos Campos, Brazil) was recorded from the VL muscle using Ag/AgCl bipolar surface electrodes (10 mm diameter) placed on participants’ right thigh (according to SENIAM project, Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles). A ground electrode was placed on the ankle of the right leg. After the aerobic exercise bout, the skin was shaved, scrubbed, and cleaned with alcohol, and the electrodes were positioned. Online EMG signals were amplified at a gain of 1000 Hz and sampled at 2000 Hz. Offline EMG signal was band-pass filtered at 20–450 Hz. An electromyometer (EMG System of Brazil) was fixed on the knee joint to establish the duration of each half-squat repetition for the EMG analysis. Knee joint angle was sampled at 2000 Hz and low-pass filtered at 10 Hz. Stationarity of the EMG signal was assessed and guaranteed by the KPSS test. Maximum EMG amplitude was obtained from root mean square (RMS) after being rectified for each movement.

**Table 1.** MNR and TV performed (in kilograms) in 4 sets at 80% 1RM in the half-squat exercise in the control condition (S) and after the running (RS) and cycling exercises (CS).*

|        | Set 1† | Set 2 | Set 3 | Set 4 | Total  
|--------|--------|-------|-------|-------|--------
| MNR    |        |       |       |       |        
| S      | 10 ± 4 | 7 ± 5 | 6 ± 3 | 6 ± 3 | 29 ± 13 
| RS     | 6 ± 3  | 6 ± 3 | 6 ± 2 | 5 ± 2 | 23 ± 9  
| CS     | 4 ± 5  | 5 ± 4 | 5 ± 2 | 4 ± 2 | 18 ± 13 
| TV (kg)|        |       |       |       |        
| S      | 1432 ± 593 | 1052 ± 624 | 873 ± 472 | 891 ± 363 | 4248 ± 1818 
| RS     | 921 ± 351 | 805 ± 405 | 742 ± 258 | 717 ± 311 | 3185 ± 1191 
| CS     | 756 ± 605 | 668 ± 573 | 623 ± 332 | 592 ± 233 | 2639 ± 1643 

*Different from S condition (\( p < 0.01 \)).
†Different from the second set of S condition (\( p < 0.05 \)).
repetition. Root mean square was normalized for each squat repetition by the RMS of the entire set. Only the second and last repetitions in each set were chosen for posterior statistical analysis.

Statistical Analyses
The data were analyzed using the Statistical Package for Social Sciences 18.0 (SPSS, Inc., Chicago, IL, USA) and presented as mean values and SDs. For all measured variables, the estimated sphericity was verified according to the W. Mauchly’s test, and the Greenhouse-Geisser correction was used when necessary. The comparison of the TV performed and MNR in the different conditions was conducted through a 2-way analysis of variance (ANOVA) (condition and set) with repeated measurements in the second factor. The comparison of VL\(_{RMS}\) in the different conditions was conducted through a 3-way ANOVA (condition, set, and repetition), with repeated measures in the last 2 factors. When a significant difference was observed, a Bonferroni post hoc test was applied. The effect size (\(\eta^2\)) of each test was calculated for all analyses. Statistical significance was set at \(p \leq 0.05\).

RESULTS
The MNR and TV performed in the strength exercise for the 3 different experimental conditions are presented in Table 1.

For the MNR there was a main effect for condition \((F = 6.82; \: p = 0.006; \: \eta^2 = 0.431)\) with higher number of repetitions performed in the S condition compared with the cycling condition \((p = 0.005)\). There was also a main effect for set \((F = 5.92; \: p = 0.003; \: \eta^2 = 0.397)\) with higher MNR performed in set 1 than during set 3 \((p = 0.007)\) and set 4 \((p = 0.005)\). Moreover, there was an interaction between condition and set \((F = 2.30; \: p = 0.047; \: \eta^2 = 0.204)\), with higher MNR performed in set 1 in the S condition than in set 1 of the RS \((p < 0.001)\) and CS \((p < 0.001)\) conditions; and also a higher number in set 2 in the S condition than during set 2 in the CS condition \((p = 0.032)\).

For the TV performed, there was a main effect for condition \((F = 6.43; \: p = 0.008; \: \eta^2 = 0.417)\), with larger TV done in the S condition compared with the CS condition \((p = 0.007)\). There was also a main effect for set \((F = 6.46; \: p = 0.002; \: \eta^2 = 0.418)\), with larger TV performed in set 1 than in sets 3 \((p = 0.005)\) and 4 \((p = 0.003)\). Moreover, there was an interaction effect between condition and set \((F = 2.40; \: p = 0.040; \: \eta^2 = 0.211)\), with larger TV performed in set 1 of the S condition than that performed in set 1 of the RS \((p < 0.001)\) and CS \((p < 0.001)\) conditions; and a larger TV during set 2 of the S condition than during set 2 of the CS \((p = 0.012)\). The VL root mean square (VL\(_{RMS}\)) in the second and last repetitions of the strength exercise for the different experimental conditions are presented in Table 2.

For the VL\(_{RMS}\), there was a main effect for repetition \((F = 24.6; \: p < 0.01; \: \eta^2 = 0.73)\), with higher values in the last repetition compared with the second one \((p = 0.01)\).

DISCUSSION
The main finding of this study was that strength endurance performance decreased when preceded by high-intensity intermittent running or cycling exercise. However, for the running condition, the strength performance was decreased only after the first exercise set, whereas for the cycling condition, the reduction in performance was present until the second set, suggesting greater interference effect generated by the cycling aerobic exercise mode. However, no alterations in the VL\(_{RMS}\) during the half-squat exercise were observed because of the running or cycling activities.

Concurrent training studies have shown impaired strength performance after running (9,32) and cycling (1,3,21,33), but to the best of our knowledge, this is the first investigation that compared the effects of high-intensity intermittent aerobic exercise modes on acute strength endurance performance.

In this investigation, there was no significant difference in VL\(_{RMS}\) during the half-squat exercise performed after the
running or cycling exercise bouts. Thus, we suggest that the decrement in strength performance after both exercise bouts was not generated by neural components. Some studies indicate that strength decrement after a high-intensity aerobic exercise is accompanied by changes in EMG signal (5,26). However, they evaluated the EMG during an isolated maximal voluntary contraction, which is more dependent on neural factors when compared with submaximal exercise execution (i.e., strength endurance) (15).

Because neural factors would not be related to the acute interference effect observed after the cycling exercise, it is conceivable to suggest that a greater participation of the anaerobic metabolism (30) and a higher carbohydrate oxidation to maintain the cycling exercise performance (7,19) were responsible for this effect.

Scott et al. (30) investigated the energy system contribution (aerobic and anaerobic) and the energy expenditure during running and cycling. Both exercises were designed to elicit a power output of 250 W over the course of 1 minute. It was observed that they had the same total energy expenditure (cycling 64.3 ± 12.2 kJ; running 63.9 ± 10.1 kJ), but during cycling, the contribution of the anaerobic metabolism was greater than in the running (28 vs. 17%, respectively). Besides, Knechtle et al. (19) found that the carbohydrate oxidation relative to body mass was greater during cycling (approximately 18% higher) than during running.

Thus, because cycling requires greater carbohydrate oxidation and contribution of the anaerobic metabolism and considering that strength performance may be dependent on these factors (29), it is possible that the greater interference effect caused by cycling is related to them. However, as we did not measure carbohydrate oxidation or anaerobic metabolism in this investigation, future studies should be conducted to test this hypothesis.

It is conceivable that the greater deleterious effect of the high-intensity intermittent cycling exercise on acute strength performance could be exacerbated during a chronic training program. However, long-term studies that compared the interference effect of running and cycling on strength performance (13,31) have shown controversial results. For example, Gergley (13) observed greater interference effect on strength development when preceded by running exercise. They divided 30 physically active individuals into 3 groups: a strength training group, a running + strength training group, and a cycling + strength training group. Both concurrent groups trained at 65% of the maximum heart rate. After 9 weeks, the group that combined running and strength training presented 24% maximum strength improvement, whereas the cycling and strength training group improved 27%. The strength training-only group presented a 39% increase in lower leg maximum dynamic strength. It is possible that the deleterious effect of eccentric action (present in the running) content on strength development might occur later, suggesting the carryover effect that may impair the performance in subsequent days (13). This phenomenon may be responsible for the greater interference effect observed after the running bout when compared with the cycling exercise.

However, Silva et al. (31) were not able to find any significant interference effect on strength development regardless of the aerobic exercise mode. They divided 44 women into 4 groups: a moderate intensity running (heart rate equivalent to 95% of the second ventilatory threshold) + strength training, a high-intensity intermittent running (1 minute at $V_{\text{O}_2\text{max}}$ velocity with 1 minute of active recovery) + strength training, a moderate intensity cycling (heart rate equivalent to 95% of the second ventilatory threshold) + strength training, and a strength training-only group. All groups increased their maximum knee extension strength (41.5, 28.1, 38.1, and 32.9%, respectively) demonstrating no interference effect on strength development independently of the intensity and aerobic exercise mode.

In this study, the acute interference effect was greater for the high-intensity intermittent cycling compared with the running exercise. The decreased performance in the strength endurance exercise was not associated with the changes in the VL EMG signal. Thus, we suggest that the mechanism behind the cycling exercise interference would be related to peripheral factors such as glycogen depletion and carbohydrate oxidation and not to neural factors. However, this study did not measure these factors, and more studies are necessary to determine the effects of high-intensity cycling exercise on muscle glycogen depletion and its association with the interference phenomenon.

**Practical Applications**

Frequently, athletes and physically active individuals are concomitantly submitted to aerobic and strength training regimens. When the strength exercise bout is preceded by an aerobic activity, it is possible to observe an impairment of strength performance (i.e., MNR or TV). This reduced performance produced in each session may decrease training stimuli when compared with strength training alone. Thus, this acute interference may contribute to the long-term impairment in strength gains after a period of concurrent training.

In this study, well-conditioned men submitted to high-intensity cycling or running exercise before a strength exercise had their strength endurance performance compromised, indicating the presence of an interference effect. However, the magnitude of the interference was greater after the cycling exercise than after the running exercise bout. Therefore, based on our results, we suggest to avoid conducting strength training immediately after an acute bout of high-intensity aerobic exercise, mainly after cycling, because greater deterioration in performance may be expected after this type of exercise. Hence, coaches and trainers should consider using lower-intensity aerobic exercise to avoid this interference effect.
Aerobic Exercise Mode on Strength Performance

Although the cycling exercise has generated greater interference, this result should be applied with caution, because the participants of this study were not runners, cyclists, or even weightlifters. It is possible that the specific adaptations of each one of these activities could affect the interference magnitude. It should be mentioned that no chronic study evaluated the effects of high-intensity intermittent cycling exercise on strength development. Thus, future studies should investigate the chronic effects of high-intensity cycling and running exercise on the interference phenomenon and strength improvement.

REFERENCES