Original Article

Effects of interval time between high-intensity intermittent aerobic exercise on strength performance: analysis in individuals with different training background

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ABSTRACT

Panissa VLG, Julio UF, Pinto e Silva CM, Andreato LV, 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.* Vol. 7, No. 4, pp. 815-825, 2012. This study aimed to analyze the effect of the time interval after high-intensity aerobic exercise on strength performance in individuals with different training backgrounds. Participants (n = 27) were divided into three groups according to their training backgrounds (aerobic, strength or concurrent) and submitted to eight sessions: (1) determination of the peak velocity (V_{peak}) during the incremental treadmill test to exhaustion and familiarization of the evaluation of maximum strength (1RM) for the half-squat; (2) 1RM determination; and (3-8) randomly assigned experimental sessions consisting of either a strength exercise (SE), four sets at 80% of the 1RM, in which maximum number of repetitions (MNR) and the total volume performed (TV) was computed, and five sessions consisting of high-intensity intermittent aerobic exercise (100% of V_{peak} - 1 min:1 min) totaling 5 km, followed by a SE with varying recovery intervals between activities (30, 60 minutes, 4, 8, and 24 hours). Comparisons for MNR and TV were made using two-way variance analysis (group and time interval) with repeated measures in the second factor. When significant differences were detected ($P < 0.05$), a Bonferroni and Dunnet post-hoc test were used. There was an effect of group for MNR, with the Aerobic Group performing a higher MNR compared to Strength Group ($P = 0.002$). Moreover, there was an effect of the time interval for MNR and TV, with reduction after 30 ($P < 0.001$ for both variables) and 60 minutes intervals ($P = 0.035$; $P = 0.007$, respectively) compared to the control condition. Thus, it is concluded that the drop in performance related to the SE activity occurred with the same magnitude and time interval for each of the groups. **Key words**: CONCURRENT TRAINING, TRAINING VOLUME, FATIGUE.

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INTRODUCTION

Recently, it has become apparent that to achieve high results during competition in some sports, it is necessary to concomitantly develop several physical capacities during the course of a training period. Among the features needed, strength and endurance are the most prominent (Reilly et al., 2009). Strength exercises are used to improve skeletal muscle contractile capacity (Costill et al., 1979) whereas aerobic exercise improves the capacity of oxygen delivery to muscle and the capacity of muscle to extract oxygen from the blood (Holloszy & Coyle, 1984). Therefore, athletes of various sports perform multiple types of exercises during their training sessions with the aim of developing aerobic fitness and strength, through specific adaptations promoted by both forms of training and to optimise performance during competitions (Baker, 2001; Balabinis et al., 2003). People seeking health maintenance also make use of the concurrent training in order to reduce body fat and increase muscle mass (Haskell et al., 2007).

The combination of aerobic exercise and strength training is known as concurrent training (CT). This nomenclature is due to antagonistic adaptations that these two types of exercises may promote (Bell et al., 2000; Hakkinen et al., 2003; Kraemer et al., 1995). In light of these various adaptations, there is great interest from researchers regarding the interference that aerobic exercise can have on strength performance because it has been demonstrated that this activity can negatively affect subsequent strength performance (Bentley et al., 2000; De Souza et al., 2007; Schiling et al., 2012; Sporer & Wenger, 2003) and strength development (Bell et al., 2000; Hickson, 1980; Kraemer et al., 1995).

The causes of impairments in strength gains are not well-established. However, some studies have reported that an acute process may be partially responsible for this response (Craig et al., 1991; Leveritt et al., 1999). The acute hypothesis suggests that there is a reduction in performance during the strength training session when the aerobic activity is previously performed, mainly when both activities are performed at intensities dependent on the peripheral mechanisms, for example, aerobic exercise performed in high-intensity (i.e.; near the $\dot{V}O_{2max}$) combined with strength exercise at intensity recommended to obtain hypertrophy (i.e.; 8-12 maximum repetition approximately) (De Souza et al., 2007; Docherty & Sporer, 2000). This would generate a decrease in the training stimulus to the force production due to an insufficient recovery between these sessions. This reduction in force production in each session, compared to situations where strength training was performed alone could partially explain the long-term impairment in strength gains.

Therefore, it is known that the utilization of the CT can generate decrease in strength gain chronically, compared with the execution of the strength training isolated (Hickson, 1980). This decrease can be due of the acute interference, because the total work performed in each session is impaired (Sale et al., 1990), and it is known that the strength development is dependent of the total volume applied (number of repetitions with a determined load) (Tan, 1999). There was evidence that longer time interval between activities can minimize the acute interference effects (Sporer & Wenger, 2003), providing a better stimulus for the strength session. Additionally, the literature has showed that individuals with different training backgrounds (runners, strength trained and physically active individuals) present distinct interference magnitude in the strength exercise performed immediately after aerobic exercise (Denadai et al., 2010).

It is possible that individuals with different training background present different responses, not only in magnitude but also in the time duration of the acute interference. Thus, it would be important to identify an optimal recovery time aiming to minimize or to nullify the interference effect in individuals with different training backgrounds. Additionally, the analyses of the interference in individuals with different background may help to understand if the phenomenon is dependent on the type of the chronic adjustment from the process in which the individuals are involved.

Thus, the aim for the present study was to verify the magnitude and duration of the acute interference, using different time recoveries (30, 60 minutes, 4, 8, and 24 hours) in individuals with different training backgrounds (aerobic trained, strength trained, and concurrently trained).

We hypothesized that the interference would be lower in aerobically trained individuals, followed by concurrently trained and strength trained athletes. This would occur because the aerobic exercise would result in greater disturbance of homeostasis in the group less familiarized with this type of activity (i.e., strength trained), followed by concurrently trained and, finally, by the group most familiarized with this type of activity (i.e., aerobically trained group).

MATERIAL AND METHODS

Participants

Twenty seven male individuals voluntarily participated in the present study after reading and signing an informed consent explaining all the risks and benefits of the present investigation. All athletes were nonsmokers, and none of them received any pharmacological treatments or had any type of neuromuscular disorder or cardiovascular, respiratory or circulatory dysfunction. The participants were selected according to their training background, and following some criteria: Aerobic Group (AG): runners with the best personal time below to 37 minutes in a 10 km race; Concurrent Group (CG): athletes of intermittent sports who were practicing systematically aerobic and strength training; Strength Group (SG): individuals experienced just in strength training. All participants had a minimum of two consecutive years of training experience. The AG was constituted by 10 middle distance runners. The CG was constituted by 9 athletes with the following experience: 6 team sport players, 1 racket sport player and 2 crossfit athletes. The SG was constituted by eight individuals with exclusive practice of the strength training (6 powerlifters and 2 weightlifters). All procedures received local ethics committee approval (16/2009).

Measures

To investigate if the total volume performed in strength session in athletes with different training backgrounds was impaired after a high-intensity intermittent aerobic session with different recovery intervals (30, 60 minutes, 4, 8, and 24 hours), eight sessions were conducted. In the first session, after body mass and height measurements, athletes were submitted to an incremental treadmill test to volitional exhaustion to determine the peak oxygen uptake ($\dot{V}O_{2peak}$) and the peak velocity attained (V_{peak}). In this same day, a maximum strength test (one repetition-maximum, 1RM) familiarization was also conducted. In the second session the athletes performed the 1RM test. Then, in different days they were submitted to the experimental sessions: one control condition strength training exercise performance (4 sets at 80% of the 1RM load for the half-squat exercise); and five sessions composed by a high-intensity intermittent aerobic exercise (1 min:1 min at V_{peak}, totaling 5km), followed by the strength exercise, using the same protocol applied in the control condition, but using different time intervals (30, 60 minutes, 4, 8, and 24 hours) between the aerobic exercise and the strength exercise. Experimental sessions were performed randomly in different days, with a minimal time interval of 3 days and a maximum of 7 days between sessions. Moreover, the athletes were required to refrain from physical exercise for 24 h prior to each session.

Procedures

Maximal aerobic test

The subjects performed an incremental treadmill test to volitional exhaustion. The initial speed was set at 6 km/h for the SG, 8 km/h for the CG, and 10 km/h for the AG. Each stage lasted 1 minute and was increased 1 $km \cdot h^{-1}$ per stage until the subject could no longer continue. The oxygen uptake was measured (k4b² Cosmed, Rome, Italy) throughout the test and the average of the last 30 s was defined as $\dot{V}O_{2peak}$. The maximal velocity reached in the test was defined as the V_{peak}. 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 following: V_{peak} = velocity of penultimate stage + (time, in seconds, remained at the last stage/60 s).

Maximum strength test

Maximum dynamic strength (1RM) for the half-squat was assessed using a Smith machine. The test was performed according to standard procedures (Brown & Weir, 2001). Briefly, the subjects began the test with a general warm up, consisting of cycling (70 rpm at 50 W) for 5 minutes, followed by two specific warm-up sets. In the first set, the athletes 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 minutes interval between each set. After the specific warm-up the subjects rested for 2 minutes and then had up to five trials to achieve the 1RM load (i.e., maximum weight that could be lifted once with proper technique), with a 3 to 5 minutes interval between trials.

For better control of the movement, during the 1RM test, both feet position and movement amplitude (90 degrees) were controlled. This standardization was repeated in the subsequent experimental sessions. The intraclass coefficient correlation between the familiarization session and the maximum strength test per se was 0.994.

Intermittent aerobic exercise

The athletes performed a warm-up at 6 km/h for the SG, 8 km/h for the CG, and 10 km/h for the AG for 5 minutes, after 2 minutes the athletes started the exercise per se. The aerobic session consisted of a 5-kilometer run on a treadmill performed intermittently, consisting of 1 minute at V_{peak} separated by 1 minute of passive recovery.

Strength exercise

The subjects performed a general warm-up consisting of cycling (70 rpm at 50 W) for 5 minutes, followed by four sets of maximum repetitions at 80% of the 1RM in the half-squat in the Smith machine. Each set was separated by 2 minutes interval. The maximum number repetitions correctly performed were counted and the volume performed was calculated (maximum number of repetitions multiplied by the weight lifted).

Analysis

The data were analyzed using the Statistical Package for Social Sciences 18.0 (SPSS Inc., Chicago, United States of American). The descriptive analyses consisted of the mean and standard deviation. For all measured variables, the sphericity estimated was verified according to the Mauchly's W test, and the Greenhouse-Geisser correction was used when necessary. The data normality was verified using the Shapiro-Wilk test. The comparison of the variables related to the characteristics of the participants (age, body mass, height and training experience), and the performance in the maximum tests (1RM, $\dot{V}O_{2peak}$, V_{peak}) among the different groups was conducted through an one-way analysis of variance. When a significant difference was observed, a Tukey's post hoc test was conducted. The comparison of the total volume performed in the different conditions was conducted through a two-way analysis of variance (group and time interval) with repeated measurements in the second factor. When a significant difference in time interval was observed a Dunnet post hoc test was conducted. When a significant difference in group or interaction was observed, a Bonferroni post hoc test was conducted. The effect size (eta-squared; η^2) of each test was calculated for all analyses. Statistical significance was set at $P < 0.05$.

RESULTS

The athletes' characteristics and their performance in the maximum tests are expressed in Table 1.

Table 1. *Age, body mass, height, maximum strength, peak oxygen uptake ($\dot{V}O_{2peak}$) and peak velocity (V_{peak}) in athletes of the aerobic group (AG), strength group (SG) and concurrent group (CG).*

	AG (n = 10)	CG (n = 9)	SG (n = 8)
Age (years)	29 ± 6	26 ± 7	26 ± 4
Body mass (kg)	70 ± 8$^{b\,c}$	84 ± 7	83 ± 4
Heigth (cm)	177 ± 6	181 ± 5	175 ± 3
Training experience (years)	8 ± 6	7 ± 6	5 ± 3
Half-squat 1RM (kg)	163 ± 19$^{b\,c}$	211 ± 25$^{a\,c}$	247 ± 15$^{a\,b}$
V_{peak} (km/h)	21.4 ± 1.4$^{b\,c}$	18.9 ± 1.5$^{a\,c}$	16.3 ± 1.1$^{a\,b}$
$\dot{V}O_{2peak}$ (ml/kg/min)	61.1 ± 5.2$^{b\,c}$	51.0 ± 7.6	44.0 ± 3.8

Data are mean ± SD; 1RM = one repetition-maximum; ^{a} = different from AG (P < 0.05); ^{b} = different from CG (P < 0.05); ^{c} = different from SG (P < 0.05).

There was no significant difference between groups for the age, height and training experience. However, there was significant difference for body mass ($F = 14$; $P < 0.001$; $\eta^2= 0.53$), with the lower values observed in the AG compared to CG ($P < 0.001$) and SG ($P = 0.001$).

For maximum strength, there was significant difference between groups ($F = 39$; $P < 0.001$; $\eta^2 = 0.76$), with higher values observed in the SG ($P < 0.001$) compared to CG ($P < 0.001$) and AG ($P < 0.001$), and CG with higher values compared to AG ($P = 0.010$). There was significant difference between groups for $\dot{V}O_{2peak}$ ($F = 16$; $P < 0.001$; $\eta^2 = 0.57$), with higher values for AG compared to CG ($P = 0.009$) and to SG ($P < 0.001$). There was a tendency to difference ($P = 0.064$) between SG and CG. Moreover, there was difference between groups in V_{peak} ($F = 30$; $P < 0.001$; $\eta^2 = 0.71$), with higher values for AG compared to CG ($P = 0.002$) and to SG ($P < 0.001$). Additionally, CG presented higher values compared to SG ($P = 0.002$).

The maximum number of repetitions in the strength exercise for the different groups in the different experimental conditions is presented in Table 2.

Table 2. *Maximum number of repetitions in four sets at 80% 1RM in the half-squat in the control condition and after 5km running with different time interval between the aerobic exercise and the strength exercise in athletes with different training backgrounds (aerobic group - AG , concurrent group - CG , and strength group - SG).*

	C [a]	30 min	60 min	4 hours	8 hours	24 hours
AG (n = 10)[b]	46 ± 16	41 ± 17	42 ± 17	48 ± 16	39 ± 14	49 ± 20
CG (n = 9)	38 ± 5	28 ± 8	34 ± 9	36 ± 5	37 ± 10	36 ± 9
SG (n = 8)	30 ± 9	18 ± 12	20 ± 12	25 ± 8	29 ± 8	26 ± 11
All groups	38 ± 13	30 ± 15	33 ± 16	37 ± 14	35 ± 12	38 ± 17

Data are mean ± SD; C = control; min = minutes; [a] = different from 30 and 60 min (P < 0.05); [b] = different from SG (P < 0.05).

For the maximum number of repetitions there was no interaction between group and time interval factor (F = 1; P = 0.27; η^2= 0.09). However, there was effect for group (F = 8; P = 0.003; η^2= 0.39), with the maximum number of repetitions performed by the AG superior to SG (P = 0.002). Moreover, there was effect for time interval factor (F = 5; P < 0.01; η^2= 0.17), with the maximum number of repetitions performed in C condition being superior to that achieved after 30 (P < 0.001) and 60 minutes (P = 0.035).

The total volume performance in the strength exercise for the different groups in the different experimental conditions is presented in Table 3.

Table 3. *Total volume performed (tonnes) in four sets at 80% 1RM in the half-squat in the control condition and after 5km running with different time interval between the aerobic exercise and the strength exercise in athletes with different training backgrounds (aerobic group - AG, concurrent group - CG, and strength group - SG).*

	C [a]	30 min	60 min	4 hours	8 hours	24 hours
AG (n = 10)	5.9 ± 1.9	5.4 ± 2.3	5.4 ± 2.1	6.2 ± 2.2	5.1 ± 2.0	6.3 ± 2.5
CG (n = 9)	6.3 ± 0.8	4.6 ± 1.0	5.7 ± 1.3	5.9 ± 1.0	6.2 ± 1.9	6.0 ± 1.3
SG (n = 8)	5.9 ± 1.9	3.8 ± 2.4	3.9 ± 2.5	5.0 ± 1.5	5.7 ± 1.7	5.2 ± 2.3
All groups	6.1 ± 1.6	4.6 ± 2.1	5.1 ± 2.1	5.7 ± 1.7	5.7 ± 1.9	5.9 ± 2.1

Data are mean ± SD; C = control; min = minutes; [a] = different from 30 and 60 min (P < 0.05).

For the total volume performed there was no interaction effect between group and time interval factors (F = 2; P = 0.082; η^2= 0.12), nor there was an effect in the group factor (F = 1; P = 0.46; η^2 = 0.06). However, there was an effect for time interval factor (F = 7; P < 0.001; η^2 = 0.22), with the total volume performed in the C condition being superior to that achieved after 30 minutes (P < 0.001) and 60 minutes (P = 0.007).

DISCUSSION

The main finding of the present study was that there was not interaction effect between group and time interval factors for the total volume performed in strength endurance exercise after high-intensity intermittent aerobic exercise in athletes with different training backgrounds. This finding means that the magnitude and duration of the interference was not dependent on the training background of the participants. Therefore, the drop in TV and MNR occurred similarly for all groups, which is contrary to our initial hypothesis that the interference would be of lesser magnitude and duration in AG, followed by CG and SG.

This hypothesis was established based on the idea that the aerobic exercise could have less impact on fatigue levels in AG when compared to other groups, since individuals with better aerobic fitness level may have lower energy costs to maintain the running activity (Bransford & Howley, 1977; Morgan et al., 1995). Additionally, during intermittent high-intensity activities like repeated sprints, individuals with better aerobic fitness level (higher values of $\dot{V}O_{2max}$) had lower decrease in performance over such a session of exercise, accompanied by greater contribution of the aerobic system and therefore less disturbance of homeostasis (Hamilton et al., 1991; Tomlin & Wenger, 2002).

However, in this study even with the possibility of the AG have performed the aerobic activity with lower physiological demand/stress than the CG and SG, the groups did not differ in the strength performance conducted after the aerobic session. Thus, our study did not corroborate the findings from Denadai et al. (2010), who demonstrated that strength trained individuals presented a more pronounced decreased percentage of torque (16.5%) in the eccentric phase when compared to runners (7.2%) and physically active individuals (6.5%). However, in the study of Denadai et al. (2010), although the strength group had a greater decrease in torque, this group had the same aerobic fitness in terms of $\dot{V}O_{2max}$ than the group of physically active individuals, who suffered a smaller decrease in torque. These findings indicate that aerobic fitness was not decisive for the magnitude of the interference, which partly corroborates the findings of our study. Moreover, the utilization of the different protocols concerning the intensity of the both activities makes difficult the comparison between the studies as this variable can modify the interference response (De Souza et al., 2007).

The mechanisms that could explain why all three groups showed similar response regarding the magnitude and duration of interference are difficult to establish, because there are no studies that were conducted with this purpose. One aspect that should be considered is that the percentage of decrease in the total volume for the intervals that resulted in decreased performance (30 minutes - SG: - 43 ± 27%, CG: - 27 ± 19%, AG - 10 ± 30%; 60 minutes - SG: - 39 ± 25%, CG: - 27 ± 8%, AG: - 34 ± 9%) presented high variability among individuals from the same group, indicating that other factors than the training background may be involved in this response.

Other important findings by the present study was that the interference occurred just after 30 and 60 minutes, while after 4, 8 and 24 hours the interference was not observed. In the literature available we found few studies that analyzed the effect of duration of interference on strength endurance (Bentley et al., 2000; Leveritt et al., 2000; Sporer & Wenger, 2003). The results obtained in the present study corroborate with the study of Leveritt et al. (2000), in which no interference effect was found after 8 hours. However, our results differ from those reported by Sporer and Wenger (2003), who found interference after 4 hours (-25%) and 8 hours (-9%) when analyzing the maximum number of repetitions. Bentley et al. (2000) also reported an interference effect after 6 hour intervals (-6%) when four maximum isometric voluntary contractions were used and it is important to highlight that the three conditions analyzed (pre, post and 6 h post) was conducted in the same day. Thus, it is difficult to compare these results with ours, as the strength exercises applied by Bentley et al. (2000) were different.

Conversely, the study by Sporer and Wenger (2003) investigated participants with a similar training background (athletes from various sports), similar aerobic exercise intensity (high-intensity intermittent exercise, i.e., 6 x 3 min:3 min at 95-100% $\dot{V}O_{2max}$ for 36 minutes) and similar strength exercise (4 sets of maximum repetitions at 75% of the 1RM on the leg press) as used in our study. However, a clear difference between the studies is the type of ergometer used in aerobic exercise, because in the studies from Sporer and Wenger (2003) and Bentley et al. (2000) the participants exercised in a cyclergometer, while in the present study the participants ran. Although there are no studies evaluating the impact of different mode of aerobic exercises (cycling, running, rowing etc.) on the subsequent strength exercise performance, it is possible to infer that the cycling exercise result in higher local fatigue than running (Bijker et al., 2002), although a chronic study demonstrated the opposity, in which the interference generated by running exercise was greater than that generated by cycling when compared to strength training only (Gergley, 2009).

The magnitude of the drop in the in the strength endurance performance verified after high-intensity intermittent exercise after the recovery intervals of the 30 minutes was 23% and 15% for 30 and 60 minutes, respectively. De Souza et al. (2007) reported a drop of the 27% 10 minutes after aerobic exercise and Leveritt and Abernethy (1999) reported a 26% drop after 30 minutes, which are similar to the magnitude found in our study.

As the source of the interference comes from aerobic activity, it is important to identify the changes of neuromuscular function after this type of activity and what effects aerobic activity has on strength performance as well as how much it affects it. In fact, studies that aimed to evaluate the muscle function after high-intensity intermittent exercise reported that the muscle function was impaired (Billaut et al., 2006).

For example, Lattier et al. (2004) studied the effect of ten 1 minute sprints at 120% of the maximum speed achieved in the progressive test with 18% inclination on the treadmill, interposed by 2 minutes of passive recovery, on force production in a knee extension exercise (maximal voluntary contraction) immediately, 45 and 65 minutes after running. Immediately after, 45 and 65 minutes after the intermittent exercise the peak torque (40.8 ± 9.9, 43.9 ± 9.0, 52.5 ± 9.3 Nm, respectively) was significantly lower than in the pre-exercise (56.3 ± 8.8 Nm). Additionally, after 65 minutes recovery the electromyographic signal amplitude (RMS) of the vastus medialis was increased 44% compared to the pre-exercise, demonstrating the incomplete restoration of the excitation-contraction coupling.

Our results also demonstrated that subjects with different training background completed the same TV during the strength training session. However, the AG was able to perform a superior MNR than the strength group at 80% 1RM half-squat. Many studies have shown that endurance athletes (runners, cyclists and triathletes) have a higher fatigue resistance in strength tasks when compared to sprinters and jumpers (Ostering et al., 1976; Paasuke et al., 1999), martial arts athletes (Häkkinen & Myllia, 1990; Garrandes et al., 2007) and weigthlifters (Häkkinen & Myllia, 1990). A possible explanation to these findings is stated into adaptations developed by aerobic training that could increase the oxidative capacity of the skeletal muscle, which could contribute to fatigue delay and to the increased work muscle ability (Costill et al., 1974; Golnick et al., 1972) and in neuromuscular responses (lesser co-activation of antagonistic muscle) (Ostering et al., 1986).

CONCLUSIONS

Based in the results obtained by this study it can be concluded that strength endurance is impaired after high-intensity intermittent aerobic exercise and that this decrease is similar in athletes with aerobic, concurrent and strength training backgrounds. The strength endurance performance decrease occurred for 30 and 60 minutes intervals with a magnitude of 23% and 15%, respectively, but disappeared after 4 h interval. Thus, when programming phases of aerobic and strength endurance training, coaches should use 4 h or longer intervals between the high-intensity intermittent aerobic exercise and strength endurance exercise. However, the training background should not be a major concerning when considering the minimum interval between these exercise sessions.

Moreover, although the recovery interval would be an important variable to minimize the acute interference it is not an assurance that the strength development will not be impaired, because there is evidence than others factors are involved in chronic process.

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REFERENCES

1. BAKER D. The effects of an in-season of concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league football players. *J Strength Cond Res*. 2001; 15:172-177. doi:10.1519/00124278-200105000-00004 [Back to text]
2. BALABINS CP, PSARAKIS CH, MOUKAS M, VASSILIOU MP, EHRAKIS PK. Early phase changes by concurrent endurance and strength training. *J Strength Cond Res*. 2003; 17:393-401. doi:10.1519/00124278-200305000-00030 [Back to text]
3. BELL GJ, SYROTUIK D, MARTIN TP. Effect of concurrent strength and endurance training on skeletal muscle properties and hormone concentrations in humans. *Eur J Appl Physiol*. 2000; 81:418-427. doi:10.1007/s004210050063 [Back to text]
4. BENTLEY DJ, SMITH PA, DAVIE JA, ZHOU S. Muscle activation of the knee extensors following high intensity endurance exercise in cyclists. *Eur J Appl Physiol*. 2000; 81:297-302. doi:10.1007/s004210050046 [Back to text]
5. BIJKER KE, GROOT G, HOLLANDER AP. Differences in leg muscle activity during running and cycling in humans. *Eur J Appl Physiol*. 2002; 87:556-561. doi:10.1007/s00421-002-0663-8 [Back to text]
6. BILLAUT F, BASSET FA, GIACOMONI M, LEMAÎTRE F, TRICOT V, FALGAIRETTE G. Effect of high-intensity intermittent cycling sprints on neuromuscular activity. *Int J Sports Med*. 2006; 27:25-30. doi:10.1055/s-2005-837488 [Back to text]
7. BRANSFORD DR, HOWLEY ET. Oxygen cost of running in trained and untrained men and women. *Med Sci Sport Exer*.1977; 9:41-44. [Abstract] [Back to text]
8. BROWN LE, WEIR J. ASEP procedures recommendation I: Accurate assessment of muscular strength and power. *J Exerc Physiol Online*. 2001; 4:1–21. [Full text] [Back to text]

9. COSTILL DL, COYLE EF, FINK WF, LESMES GR, WITZMANN FA. Adaptations in skeletal muscle following strength training. *J Appl Physiol*. 1979; 46:96-99. [Abstract] [Back to text]
10. CRAIG BW, LUCAS J, POHLMAN R, STELLING, H. The effects of running, weightlifting and a combination of both on growth hormone release. *J Appl Sport Sci Res*. 1991; 5:198-203. [Abstract] [Back to text]
11. 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; 21:1286-1290. doi:10.1519/00124278-200711000-00053 [Back to text]
12. DENADAI BS, CORVINO RB, GRECO CC. Effect of a previous high intensity running exercise on isokinetic muscular strength in individuals with different training backgrounds. *Isokinet Exerc Sci*. 2010; 18:15-21. doi:10.3233/IES-2010-0362 [Back to text]
13. DOCHERTY D, SPORER B. A proposed model for examining the interference phenomenon between concurrent aerobic and strength training. *Sports Med*. 2000; 30:385-394. doi:10.2165/00007256-200030060-00001 [Back to text]
14. GARRANDES F, COLSON SS, PENSINI M, SEYNNES O, LEGROS P. Neuromuscular fatigue profile in endurance-trained and power-trained athletes. *Med Sci Sport Exer*. 2007; 39:149-158. doi:10.1249/01.mss.0000240322.00782.c9 [Back to text]
15. GERGLEY JC. Comparison of two lower-body modes of endurance training on lower-body strength development while concurrently training. *J Strength Cond Res*. 2009; 23:979-987. doi:10.1519/JSC.0b013e3181a0629d [Back to text]
16. GOLLNICK PD, ARMSTRONG RB, SAUBERT IV CW, PIEHL K, SALFIN B. Enzyme activity and fiber composition in skeletal muscle of untrained and trained men. *J Appl Physiol*. 1972; 33:312-319. [Full text] [Back to text]
17. HÄKKINEN K, ALEN M, KRAEMER WJ, GOROSTIAGA E, IZQUIERDO M, RUSKO H. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *Eur J Appl Physiol*. 2003; 89:42-52. doi:10.1007/s00421-002-0751-9 [Back to text]
18. HÄKKINEN K, MYLLYIÄ, E. Acute effects of muscle fatigue and recovery on force production and relaxation in endurance, power and strength athletes. *J Sport Med Phys Fit*. 1990; 30:5-12. [Abstract] [Back to text]
19. HAMILTON AL, NEVILL ME, BROOKS S, WILLIAMS C. Physiological responses to maximal intermittent exercise: differences between endurance-trained runners and game players. *J Sport Sci*. 1991; 9:371-382. doi:10.1080/02640419108729897 [Back to text]
20. HASKELL WL, LEE IM, PATE RR, POWELL KE, BLAIR SN, FRANKLIN BA. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sport Exer*. 2007; 39:1423-1434. doi:10.1249/mss.0b013e3180616b27 [Back to text]
21. HICKSON RC. Interference of strength development by simultaneously training for strength and endurance. *Eur J Appl Physiol*. 1980; 45:255-263. doi:10.1007/BF00421333 [Back to text]
22. HOLLOSZY JO, COYLE EF. Adaptations of skeletal muscle to endurance exercise and their metabolic consequences. *J Appl Physiol*. 1984; 56:831-838. [Abstract] [Back to text]
23. KRAEMER WJ, PATTON JF, GORDON SE, HARMAN EA, DESCHENES MR, REYNOLDS K. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *J Appl Physiol*. 1995; 78: 976-989. [Abstract] [Back to text]
24. LATTIER G, MILLET GY, MARTIN A, MARTIN V. Fatigue and recovery after high intensity exercise. Part II: recovery interventions. *Int J Sports Med*. 2004; 25:509-515. doi:10.1055/s-2004-820946 [Back to text]

25. LEVERITT M, ABERNETHY PJ, BARRY BK, LOGAN, PA. Concurrent strength and endurance training: a review. *Sports Med*. 1999; 28:413-427. doi:10.2165/00007256-199928060-00004 [Back to text]
26. LEVERITT M, ABERNETHY PJ. Acute effects of high intensity endurance exercise on subsequent resistance activity. *J Strength Cond Res*. 1999; 13:47-51. doi:10.1519/00124278-199902000-00009 [Back to text]
27. LEVERITT M, MACLAUGHLIN H, ABERNETHY PJ. Changes in leg strength 8 and 32 h after endurance exercise. *J Sport Sci*. 2000; 18:865-871. doi:10.1080/026404100750017797 [Back to text]
28. MORGAN DW, BRANSFORD DR, COSTILL DL, DANIELS JT, HOWLEY ET, KRAHENBUHL GS. Variation in the aerobic demand of running among trained and untrained subjects. *Med Sci Sport Exer*. 1995; 27:404-409. doi:10.1249/00005768-199503000-00017 [Back to text]
29. OSTERNIG LR, HAMILL J, LANDER JE, ROBERTSON R. Co-activation of sprinter and distance runner muscles in isokinetic exercise. *Med Sci Sport Exer*. 1986: 18:431-435. [Abstract] [Back to text]
30. PAASUKE M, ERELINE J, GAPEYEVA H. Neuromuscular fatigue during repeated exhaustive submaximal static contractions of knee extensor muscles in endurance-trained, power-trained and untrained men. *Acta Physiol Scand*. 1999; 166:319-326. [Abstract] [Back to text]
31. REILLY R, MORRIS T, WHYTE G. The specificity of training prescription and physiological assessment: a review. *J Sport Sci*. 2009; 27:575-589. doi:10.1080/02640410902729741 [Back to text]
32. SALE DG, MACDOUGAL JD, JACOBS I, GARNER S. Interaction between concurrent strength and endurance training. *J Appl Physiol*. 1990; 68:260-270. [Abstract] [Back to text]
33. SCHILING BK, REED JP, MURLASITS Z. Acute neuromuscular and metabolic responses to concurrent endurance and resistance exercise. *J Strength Cond Res*. 2012; May 24. [Epub ahead of print]. doi:10.1519/JSC.0b013e31825c2d3e [Back to text]
34. SPORER BC, WENGER H. Effects of aerobic exercise on strength performance following various periods of recovery. *J Strength Cond Res*. 2003; 17:638-644. doi:10.1519/00124278-200311000-00003 [Back to text]
35. TAN B. Manipulating resistance training program variables to optimize maximum strength in men: a review. *J Strength Cond Res*. 1999; 13:289-304. doi:10.1519/00124278-199908000-00019 [Back to text]
36. TOMLIN DL, WENGER HA. The relationship between aerobic fitness, power maintenance and oxygen consumption during intense intermittent exercise. *J Sci Med Sport*. 2002; 5:194-203. doi:10.1016/S1440-2440(02)80004-4 [Back to text]