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Effects of Aerobic Exercise on Strength Performance Following Various Periods of Recovery

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ABSTRACT

The purpose of this study was to determine if the type and intensity of aerobic training affects performance in a subsequent strength-training session after varying periods of recovery. Sixteen male subjects participated in the study and were divided into 2 groups based on aerobic training, high-intensity intervals (MAX $n = 8$) and continuous submaximal (SUB $n = 8$). Each subject performed 4 sets of both bench press and leg press at approximately 75% 1 repetition maximum (1RM) following aerobic training with recovery periods of 4, 8, and 24 hours, as well as once in a control condition. Both the 4- and 8-hour conditions resulted in fewer total leg press repetitions than the control and 24-hour conditions. There was no difference between both the control and 24-hour conditions. No main effect was shown with respect to the type of aerobic training. It was concluded that when aerobic training precedes strength training, the volume of work that can be performed is diminished for up to 8 hours. This impairment appears to be localized to the muscle groups involved in the aerobic training.

Key Words: concurrent, training, interference, endurance

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Introduction

Many sports require athletes to possess high levels of both muscular strength and aerobic fitness in order to be competitive. Due to time restrictions and sport demands, athletes may be required to train for both fitness components during the same training phase (hereafter referred to as concurrent training). Concurrent training has been shown to result in impaired strength improvements when compared with strength training alone (8, 10–12). However, strength improvements have also been shown to be unaffected by concurrent training (2, 18, 22), and 1 study has shown inhibition of aerobic power development (19). The specific responses to concurrent training appear to be inconsistent, although it is generally accepted that concurrent training results in impaired strength improvements with minimal or no impact on aerobic development (4, 16).

The physiological causes of these compromised strength gains are not well understood. Several hypotheses have been proposed based on research evidence of the physiological requirements of and adaptations to strength or endurance training when performed exclusively. The fatigue hypothesis (5, 16) suggests that under concurrent training conditions, the amount of work that can be performed in each strength-training session is reduced due to fatigue from prior aerobic training (5, 16). This may result in compromised strength improvements over the course of a training program. Only 1 study has examined the long-term effects of different recovery periods between strength and aerobic training sessions over the course of a training program. Sale et al. (22) examined the effects of recovery on strength from both same-day and alternate-day concurrent training. Although the training programs were the same, alternate-day training showed significantly greater improvements in maximal leg press strength than same-day training at both 10 and 20 weeks. Furthermore, average training volume for each strength-training session was significantly lower for the same-day training group although the sequence of aerobic and strength training alternated each session. They suggested that 24 hours of recovery following aerobic training results in improved ability of the muscle to perform work as compared with 30 minutes (22).

Other studies provide insight into how long fatigue from prior aerobic training may affect strength-training volume (1, 15, 17). Aerobic training at a variety of durations and intensities compromises both isotonic and isokinetic strength performance at both 30 minutes and 4 hours (1, 15). It has also been shown that when recovery from aerobic exercise is increased to 8 hours, strength performance is not compromised (17). However, it is difficult to determine a recovery timeline from these studies as they vary in both exercise and testing protocols. Both the type and intensity of either training or testing may affect the extent to which strength will appear to be compromised (6, 16).

As previously mentioned, concurrent strength and aerobic training results in compromised strength gains (8, 11, 12, 22). Compromised strength gains appear to be more pronounced when strength training follows aerobic training (3), and this may be due to a decreased ability of the muscle to perform work in a subsequent strength-training session (1, 15, 22). The optimum time required between an aerobic and strength-training session to ensure adequate recovery of the working muscles has not yet been determined. Therefore, the purpose of this study was to examine the effects of 2 different types of aerobic training on subsequent strength-training performance under varying durations of recovery and to determine if there is a muscle-specific effect.

Methods

Experimental Approach to the Problem

This study was designed to accomplish 3 objectives. The first objective is to determine if prior aerobic exercise compromises strength performance, and if so, how long this compromise lasts for. To achieve this, each subject underwent 3 different recovery conditions from aerobic exercise as well as a control condition of no aerobic exercise prior to strength training. The second objective was to determine if the intensity of aerobic training differently affected subsequent strength performance. This was achieved by dividing all subjects into 2 groups based on aerobic training intensity. The last objective was to determine whether or not acute strength performance is differentially affected depending on the muscle groups used in prior aerobic exercise. By utilizing a cycle ergometer for aerobic exercise, isolation of lower-body muscles was achieved, and we were therefore able to compare between the affects on upper- (bench press) and lower-body (leg press) strength performance. It was expected that with inadequate recovery time, aerobic exercise would minimize the amount of repetitions that can be performed in a subsequent strength-training session. Furthermore, compromises would be limited to the muscles used in prior aerobic exercise, and it was expected that high-intensity aerobic exercise would have a greater compromise than submaximal aerobic exercise.

Subjects

Following approval by the University of Victoria Human Research Ethics Committee, 17 male subjects were recruited from the university athletic community. All were actively involved in sports and were therefore accustomed to training at maximal intensities. The 17 male subjects included 2 varsity rugby players; 3 hockey players (Junior A and up); 1 varsity rower; 3 varsity tennis players; a soccer player; and 7 recreational athletes (a variety of sports including soccer, hockey, mountain biking, and jogging). All subjects were strength training at the time of the study (2–3 times per week for both upper and lower body) and for at least 6 consecutive months in the 2 years prior. Subjects also had previous experience performing high-intensity aerobic intervals. All subjects were medically screened with a Par-Q, signed an informed consent, and the confidentiality of results was assured.

One subject withdrew prior to completing the study due to an injury, and therefore only 16 subjects completed all training and testing conditions. One subject performed a dumbbell press instead of the bench press due to a previous shoulder injury.

Experiment Design

The study followed a randomized within-subjects design. Subjects were randomly divided into 1 of 2 groups, a high-intensity aerobic interval training group (MAX) or a submaximal aerobic continuous training group (SUB). Subjects were then required to visit the laboratory on 9 different occasions. One session required an initial 1 repetition maximum (1RM) leg press and bench press test to determine loads to be used in strength-training sessions. A second session was used to determine the cycle $\dot{V}O_2$max of each subject and power output at $\dot{V}O_2$max (MAPW). The remainder of the training and testing sessions (3 aerobic training sessions and 4 strength testing sessions) were randomized with a minimum of 72 hours rest between each strength testing session. All strength testing sessions were performed during a 3-hour window in the evening to account for diurnal effects. Both aerobic and strength training outside of the study were not performed 48 hours prior to a strength testing session, and subjects were requested to keep other activities to a minimum. Training and testing sessions were arranged around team training and competitive schedules. Five Monark cycle ergometers were calibrated prior to, during, and at the end of the study to ensure accuracy and consistency of the training intensities. All subjects performed strength testing sessions on the same incline leg press (BodyMasters) and bench press.

$\dot{V}O_2$max Test. Mass (kilograms) and height (centimeters) were obtained prior to the $\dot{V}O_2$max test. Subjects were instructed to do their own stretching before the cycling test began. The test was an incremental test and began with one 2-minute stage between 70 and 80 W. Each stage thereafter lasted 1 minute, and resistance was increased by 35–40 W for each stage until the subject could no longer continue. Pedal revolutions (rpm) were maintained between 70 and 80 rpm. Oxygen consumption was measured using a Sensormedics Vmax System and was expressed relative to body

mass. $\dot{V}O_2$max was considered to have been achieved when 2 or more of the following criteria had occurred: (a) there was a plateau (<2 ml·kg^{-1}·min^{-1} increase) or decrease in oxygen consumption with a subsequent increase in workload; (b) age-predicted maximum heart rate had been achieved; (c) a respiratory quotient of 1.1 or greater had been achieved; (d) the subject reached fatigue. Revolutions per minute were recorded at the end of each stage and, combined with resistance, was used to determine MAPW in watts. Maximum heart rate (HRMAX) was monitored and recorded using a Polar Sport heart rate monitor and was then used to monitor the intensity of the aerobic training sessions.

MAX Aerobic Training. Subjects in group MAX performed interval training consisting of a 5-minute warm-up, six 3-minute exercise intervals separated by 3-minute recovery periods, and a 5-minute cool-down. During warm-up, cool-down, and recovery periods, training intensity was at approximately 40% MAPW. The first exercise interval was performed at approximately 95–100% MAPW for the entire 3 minutes, whereas subsequent intervals were adjusted to both ensure that the subject was training at HRMAX and was able to complete the training session. None of the intervals, however, were reduced to below approximately 85% of the load achieved at MAPW, and the same loading protocol was used for the next 2 aerobic training sessions to ensure consistency. Revolutions per minute were recorded at the first, second, and third minute of each exercise interval and were used to calculate average watts and work performed during each exercise interval. These were in turn used to calculate the average watts and work (joules) performed during each training session. Average rpm were also recorded during each 3-minute recovery period. Interval training was designed to reflect how athletes train for maximal aerobic power and to optimize time spent at $\dot{V}O_2$max (20).

SUB Aerobic Training. Subjects in group SUB performed submaximal aerobic training consisting of a 5-minute warm-up, 36 minutes at approximately 70% MAPW, and a 5-minute cool-down. Revolutions per minute were recorded at 6-minute intervals of the submaximal training portion. Average watts and work per training session were calculated to ensure consistency. SUB training was designed to equal the duration of MAX aerobic training.

One Repetition Maximum Strength Testing. Subjects were required to perform a general warm-up consisting of 5 minutes of cycling and stretches of their choice. All leg press testing was performed on a BodyMasters incline leg press of approximately 45°, whereas the bench press was performed on a standard bench press using a 45-pound Olympic-style bar. Leg press testing preceded bench press testing, and both followed the same protocol. Subjects were required to perform between 6 and 8 repetitions of approximately 50% their 1RM followed by a 4-minute rest, and then perform between 2 and 4 repetitions of approximately 75% their 1RM. From this point forward, a 4-minute rest was allotted between subsequent attempts until 1RM was reached. The 1RM leg press was performed as a concentric contraction from a joint angle of 90° at the knee. At the end of the testing session, subjects were requested to hold the empty sled at a 90° angle at the knee so that the position could be recorded and used in testing. For the bench press, subjects were required to lower the weight controlled to within 2.5 cm of their chest and raise the weight to full extension of the arms. Placement of the hands was at the discretion of the subject; however, the distance between the hands was measured, and this was required to be constant in all bench press testing sessions.

Strength Testing. Strength testing was designed to mimic a typical resistance-training session. Subjects were required to performed 4 sets of leg press followed by 4 sets of bench press at a load of approximately 75% 1RM. Each set was separated by a recovery period of 3 minutes, with all sets of leg press being performed prior to the bench press. All subjects performed a standardized warm-up that was the same for each testing session. A complete repetition for the leg press consisted of lowering the weight to the 90° marker and raising the weight back to its original position. Verbal confirmation was given when the 90° marker had been reached and subjects were encouraged to wait until confirmation was received prior to raising the weight. A complete repetition for the bench press consisted of lowering the weight in a controlled manner to within 2.5 cm of the chest and raising the weight to full extension of the arms. A trained assistant who was blind to the condition of each subject counted all complete repetitions. Total repetitions were counted for each set and testing session.

Statistical Analyses

The statistical analyses included the calculation of descriptive statistics for comparisons between groups using independent *t*-tests with a Bonferroni adjustment. A repeated measures analysis of variance (ANOVA; 2 × 4, group × time) was conducted for each of the dependent variables of leg press (LP) and bench press (BP) using the mean of total repetitions per training session (MTRL and MTRB, respectively) under each condition. No effect was shown for type of aerobic training, so therefore both MAX and SUB were combined into 1 group (COMB). Paired *t*-tests were conducted for post hoc tests for which a main effect was shown. A paired *t*-test was used as it favors making a type 1 error at the expense of a type 2 error. Due to the high variability whenever using human subjects in these exercise settings and since the cost of making

Table 1. Mean, range, and ± standard error (*SE*) for age, height, and weight of both MAX ($n = 8$) and SUB ($n = 8$) groups.*

	Age (yrs)	Height (cm)	Weight (kg)
MAX			
Mean	25	179.4	83.0
Range	19–29	171.5–189	70.4–91.0
SE	1	1.8	2.1
SUB			
Mean	26	179.4	82.0
Range	20–32	173–191	73.0–97.5
SE	1	2.5	2.8

* MAX = high-intensity aerobic interval training group; SUB = submaximal aerobic continuous training group.

Table 2. Mean, range, and ± standard error (*SE*) for $\dot{V}O_2max$, power output at $\dot{V}O_2max$ (MAPW), maximum leg press (MLP), and maximum bench press (MBP) of both MAX ($n = 8$) and SUB ($n = 8$) groups.*

	$\dot{V}O_2max$ (ml ·kg^{-1}·min^{-1})	MAPW (W)	MLP (lbs)	MBP (lbs)
MAX				
Mean	55.8	382	864	231
Range	45.9–62.7	311–451	585–1,140	180–335
SE	1.8	16	68	17
SUB				
Mean	57.5	384	783	219
Range	44.4–75.8	312–468	655–1,080	165–305
SE	3.2	18	52	15

* MAX = high-intensity aerobic interval training group; SUB = submaximal aerobic continuous training group.

this type of error is minimal, this approach was taken. An α level of 0.05 was used for all statistical tests.

Results

Subjects

The 16 male subjects included 2 rugby players, 3 hockey players, 1 rower, 2 tennis players, a soccer player, and 7 recreational athletes. Both Tables 1 and 2 summarize the pretest values and characteristics of all subjects in the high-intensity, interval aerobic training group (MAX) and the submaximal, continuous aerobic training group (SUB). No significant differences were found between each group on any of the measures.

Aerobic Training

Mean power output per aerobic training session (MPO), and mean session training work (TW) were significantly different between the 2 groups (Table 3). Group MAX worked at a significantly higher wattage (314 vs. 248 W, $p = 0.002$) while performing significantly less TW over the 36 minutes (339 kJ vs. 536 kJ, $p < 0.001$). Work between groups when recovery intervals were included (TWIR) was not different (486 vs. 536 kJ, $p = 0.151$).

Table 3. Mean power output (MPO), mean training work (TW), mean training work including recovery (TWIR), and ± standard error (*SE*) in each aerobic training session for both MAX and SUB groups.†

	MPO (W)	TW (J)	TWIR (J)
MAX	314*	339,066**	485,576
SE	11	12,588	16,744
SUB	248*	535,808**	535,808
SE	13	29,302	29,302

† MAX = high-intensity aerobic interval training group; SUB = submaximal aerobic continuous training group.
*,** Denotes significant differences between conditions ($p < 0.05$).

Table 4. Mean volume in total repetitions over 4 sets and ± standard error (*SE*) for leg press (MTRL) of all subjects (COMB).

	Control	4-hour	8-hour	24-hour
COMB ($n = 16$)	48	36*,***	44*,**,***	49
SE	3	3	3	3

* Significantly different from control, $p < 0.05$.
** Significantly different from 4-hour, $p < 0.05$.
*** Significantly different from 24-hour, $p < 0.05$.

Leg Press

MTRL over 4 sets was significantly affected by the amount of recovery time between aerobic- and strength-training sessions ($p < 0.001$). Type of aerobic training (MAX, SUB) showed no main effect on MTRL ($p = 0.71$), nor was there any interaction between type of training and recovery condition ($p = 0.97$). Retrospective analysis using control condition as representative of population revealed an effect size and power of 1.2 and 0.8, respectively, for MTRL. At both 4 and 8 hours, repetitions were lower (36 repetitions, 25% decrease in volume, $p < 0.001$; and 44 repetitions, 9% decrease in volume, $p < 0.005$, respectively) when compared with the control (48 repetitions; Table 4). MTRL was higher when recovery time was increased from 4 to 8 hours (7 repetitions, 22%, $p = 0.002$) and from 8 to 24 hours (5 repetitions, 12%, $p = 0.009$). There was no difference in MTRL between the control and 24-hour recovery conditions (48 vs. 49, $p = 0.62$).

Table 5. Mean volume in total repetitions over 4 sets and ± standard error (*SE*) bench press (MTRB) of all subjects (COMB).

	Control	4-hour	8-hour	24-hour
COMB (n = 16)	32	32	32	32
SE	1	1	1	1

The general trend was that as recovery time from aerobic exercise increased up to 24 hours, so did MTRL.

Bench Press

MTRB over 4 sets was not affected by either the amount of recovery time from aerobic training or type of aerobic training ($p = 0.97$ and $p = 0.69$, respectively). Mean repetitions per condition are shown for all subjects in Table 5.

Discussion

This study demonstrated that when strength training follows aerobic training, the volume of work (total repetitions over 4 sets at approximately 75% 1RM) that can be performed in a strength-training session is diminished. The extent to which volume is compromised appears to be both dependent on the length of the recovery period between training sessions and limited to the muscle groups utilized in aerobic training. Although it can be assumed that this is due to an increased level of muscular fatigue, without additional measures such as muscle biopsies and electromyography readings, it is difficult to interpret the cause of such fatigue (hydrogen ion, energy supply, neural fatigue, or structural damage).

The fatigue hypothesis states that under concurrent training conditions, the volume that can be performed in each strength-training session is reduced due to fatigue from prior aerobic training, thereby resulting in impaired strength gains (5, 16). Understanding that total volume is an important factor in optimizing the strength-training response (16), a reduction in volume may be responsible for the compromised improvements in strength seen in concurrent training studies (8, 11–13).

The major finding in this study is that the volume of strength training that can be performed in previously aerobically trained muscles is dependent on the length of recovery between aerobic and strength-training sessions. Aerobic cycling resulted in decreased volume performed in the leg press exercise (MTRL) with both 4 and 8 hours of recovery between sessions (25% and 9%, respectively). When 24 hours of recovery was allotted, MTRL was equal to that of the control condition. As recovery time increased, MTRL also increased (Table 1).

This finding is in agreement with the current literature. Leveritt and Abernethy (15) showed that isokinetic and isotonic strength were both impaired 30 minutes after high-intensity aerobic interval exercise (5 minutes at 60–100% $\dot{V}O_2$max). Isotonic strength appeared to be affected to a greater extent than isokinetic strength. A 27% drop in total repetitions over 3 sets at 80% 1RM of the back squat was observed. As well, Abernethy (1) demonstrated that isokinetic strength was impaired for up to 4 hours following high-intensity aerobic interval training similar to Leveritt and Abernethy (15). If isotonic strength is affected by prior aerobic training to a greater extent than is isokinetic strength (15), it could be assumed that isotonic strength would be impaired for up to 4 hours as well. The current findings support this notion and further suggest that compromises in strength may last up to 8 hours postaerobic training.

Only 1 study examined the effect of prior aerobic activity on subsequent strength performances with recovery periods greater than 4 hours. Leveritt et al. (17) demonstrated that isokinetic, isometric, and isotonic strength performance was not affected both 8 and 32 hours after aerobic exercise. This is in disagreement with the current finding that the amount of leg press repetitions that can performed is reduced with 8 hours of recovery. Differences between the training and testing protocols combined are likely responsible for inconsistencies in findings. Leveritt et al. (17) measured isotonic strength performance with 2 sets of leg extensions. The movement patterns of a leg press and leg extension are slightly different, with the leg press being more similar to the movement used in cycling, albeit bilateral. Second, the inclusion of 2 extra sets in the present study may have accounted for the difference in findings. The current study used a 4-set protocol, which is often used in strength-training protocols.

The results also suggest that if 24 hours of recovery are allotted between aerobic and strength training, no loss in strength-training volume will be experienced. This is in agreement with Sale et al. (22) who demonstrated that same-day concurrent training resulted in significantly less volume per strength-training session when compared with alternate-day training. Sale et al. (22) utilized similar strength (15RM–20RM) and aerobic (90–100% $\dot{V}O_2$max intervals) training protocols as the current study. Alternate-day training also resulted in significantly greater improvements in strength than same-day training over 20 weeks. It was hypothesized that compromised gains may be reflective of the compromised volume per strength-training session that was experienced with same-day training. Although Sale et al. (22) did not use a control group to determine whether or not 24 hours was sufficient time for complete recovery, these findings are in agreement with the current finding that longer recovery periods allow for a greater volume of strength training to be performed.

The length of recovery periods in other concurrent training studies either vary or are unclear, making it difficult to show relationships to the present findings and those of Sale et al. (22). However, conclusions linking decreased volume in a single session to compromised strength improvements over a training study should be made with caution. Fatigue, as well, has been shown to be an important factor contributing to the strength-training stimulus (21). If the muscle is taken to fatigue at a certain load in each set, it is possible that the training effect has occurred regardless of the number of repetitions. Further research is necessary to determine the extent to which fatigue and volume contribute to the strength stimulus.

It is also possible that the number of sets used in the current study may have hidden any fatigue that may still have been present at 24 hours. Multiple sets of multiple exercises are generally used when training for strength of a specific muscle group. Had a second exercise or more sets been used, a lower MTRL may have been seen at 24 hours when compared with the control.

Differences in MTRL between recovery conditions are likely due to different levels of fatigue in the muscle. Muscular fatigue is defined as the point at which a particular force level can no longer be maintained (10) and may be affected by increases in H^+ due to lactic acid dissociation, decreases in energy substrates, decreases in neural drive, and structural damage (9, 10, 23). Without specific cellular and electrical measurements, it is difficult to determine the nature of the fatigue in both the 4- and 8-hour conditions.

The second major finding in this study is that the effect of recovery on strength performance following aerobic exercise is similar regardless if the aerobic exercise is high-intensity interval or submaximal continuous training. The stronger, more powerful fast-twitch (FT) muscle fibers are primarily responsible for producing the force required when strength training. Although aerobic training primarily recruits slow-twitch (ST) fibers, as intensity of training increases, FT muscle fibers are taxed to a greater extent (7). It would be expected, then, that higher-intensity aerobic training would result in a greater amount of fatigue prior to strength training. However, no effect of type of aerobic training was shown on MTRL in the current study. This is likely due to the fact that when total work was calculated for both MAX (TWIR) and SUB, there was no significant difference in total work performed between the 2 (Table 3). Abernethy (1) demonstrated a similar response using slightly different training and testing protocols. Using slow continuous cycling (150 minutes at ~35% $\dot{V}O_2$max) and interval training (5 repetitions of 5 minutes at 60–100% $\dot{V}O_2$max), it was shown that isokinetic strength at a variety of speeds was similarly affected by both training conditions. Unfortunately, no calculation of total work performed during aerobic training performed by each group was reported.

A third major finding in this study is that strength impairments appear to be limited to the muscle groups used in prior aerobic training. There was no difference in MTRB when length of recovery period was changed. The mechanisms of muscular fatigue are specific to the muscle groups utilized and would not be expected in the muscles of the upper body when aerobic training was primarily performed with the lower body. Currently there appears to be no research examining the acute effects of aerobic training on the strength of nonaerobically exercised muscle groups. Some training studies have examined the effects of concurrent training on upper-body strength using lower-body muscle groups for aerobic training (11, 14). Both Hennessy and Watson (11) and Kraemer et al. (14) demonstrated that improvements in upper-body strength were not affected by concurrent training. It is possible that concurrently trained groups in both of these training studies were able to maintain similar volumes of upper-body training as strength-only–trained groups. However, this conclusion is made with caution as both of these studies utilized multiple strength-training intensities that were different than the present study. Sequence of training also varied in both training studies. Kraemer et al. (14) sequenced aerobic training 5–6 hours after strength sessions, whereas Hennessy and Watson (11) utilized both same- and alternate-day training.

In conclusion, this study has 3 major findings. Strength performance is impaired for up to 8 hours following aerobic exercise, and this effect is similar for both high-intensity interval and submaximal continuous aerobic exercise. Also, this effect is specific to the muscle groups aerobically trained. Future research is necessary to determine if this acute strength impairment leads to compromised strength gains over the course of a training period. Additionally, research examining direct physiological measures may provide insight as to the cause of fatigue following aerobic training that results in compromised strength performance.

Practical Applications

The results of this study suggest that approximately 40 minutes of preceding aerobic exercise can compromise strength performance for up to 8 hours. This compromise appears to be specific to muscle groups used in prior aerobic training and is similar following both high-intensity interval and submaximal continuous aerobic exercise. Whether or not this compromises strength development over the course of a training program is unclear. This does, however, identify 2 factors to consider when scheduling training sessions for athletes requiring improvements in aerobic capacity and muscular strength. First, if optimum performance is desired in a strength-training session, it is suggested that recovery periods of 8 hours be allotted following aerobic exercise, that different muscle groups are utilized, or that strength training precede aerobic training. Second, maximal aerobic training appears to similarly affect strength performance as does submaximal aerobic training when equated for duration. This provides the coach with a wide range of training intensities to prescribe when aerobic training must precede strength training. Although this study has identified some key training variables when utilizing concurrent training, the scheduling of both strength and aerobic training will ultimately depend on the goals of the athlete and the demands of the sport.

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