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The acute effects of combining resistive and endurance exercise regimens

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THE ACUTE EFFECTS OF COMBINING RESISTIVE AND ENDURANCE EXERCISE REGIMENS

by

Craig Edward Todd

An Abstract

of a thesis submitted in partial fulfillment
of the requirements for the degree of
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ABSTRACT

The present study investigated the acute interactions of performing concurrent strength and endurance exercises. Eighteen trained male college-aged subjects (age = 22.4 ± 4.2 yrs) completed two exercise sessions. Two groups performed a strength protocol consisting of five strength exercises for the upper body (UB) or the lower body (LB), and an endurance protocol consisting of a 30 minute cycle ride at a standardized perceived exertion (RPE). The protocols were performed in immediate succession, and order of performance was reversed in the second session. The number of repetitions performed by LB decreased from 10.4 to 8.4 following the 30 minute cycle ride ($p < 0.002$), while the number of repetitions performed by UB did not change with order of performance. The average load chosen by the subjects during the cycle ride decreased from 141.3 W to 132.7 W when preceded by strength training. Therefore, the results indicate that LB strength was acutely compromised when preceded by the endurance protocol, whereas UB strength was not. In addition, endurance was acutely compromised when preceded by strength exercises in both the LB and UB groups. It is speculated that high blood lactate levels caused by

strength exercises may have affected the subject's perception of exertion during the subsequent endurance effort.

In conclusion, combining strength and endurance exercises in a single session impairs strength performance in the muscles used during prior endurance exercise. However, endurance performance is impaired regardless of which muscles are used during prior strength exercise.

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A Thesis Presented to the Faculty of
the School of Health Sciences
and Human Performance
Ithaca College

In Partial Fulfillment of the
Requirements for the Degree
Master of Science

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by

Craig Edward Todd

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Ithaca College

School of Health Sciences and Human Performance

Ithaca, New York

CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science Thesis of

Craig Edward Todd

submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Health Sciences and Human Performance at Ithaca College has been approved.

Thesis Advisor:

Committee Member:

Candidate:

Chairperson, Graduate Programs in Exercise and Sport Sciences:

Dean of Graduate Studies:

Date: May 9, 1996

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DEDICATION

This thesis is dedicated to the memory of Dr. William B. Koch. Dr. Koch was my advisor, mentor, and a good friend. He convinced me to attend Ithaca College, and he will be greatly missed.

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Introduction

In many training programs, athletes are expected to simultaneously improve both muscular strength and endurance. This is also frequently the goal of personal fitness programs (American College of Sports Medicine, 1995). To realize these goals, concurrent strength (e.g., weightlifting) and endurance (e.g., running) training regimens are often employed. However, physiological adaptations with either form of training may hamper optimal progress in the other. Many studies have investigated the chronic effects of simultaneously training for strength and endurance (Dudley & Fleck, 1987; Hickson, 1980; Hickson, Dvorak, Gorostiaga, Kurowski, & Foster, 1988; Hunter, Demment, & Miller, 1987; Nelson, Arnall, Loy, Silvester, & Conlee, 1990; Sale, MacDougall, Jacobs, & Garner, 1990). The majority of these investigations have shown that, with concurrent training, endurance training impedes strength gains whereas strength training does not affect endurance gains. The reasons offered for this chronic interference are further detailed in the review of literature (Appendix A).

Acute responses to concurrent exercises may help to explain the interference observed with long-term concurrent training. However, there is a lack of information describing the acute effects of combining strength and endurance exercises. There are several possible mechanisms for acute negative interactions between the two forms of exercise. The responses that may cause these interactions include substrate depletion (e.g., creatine phosphate, intramuscular triglycerides, and glycogen), waste product accumulation (e.g., lactic acid), hormone level changes (e.g., catecholamines, insulin), and muscle fiber fatigue (Abernethy, Jürimäe, Logan, Taylor, & Thayer, 1994; Fisher & Jensen, 1990; Miller, 1992). Depending upon which of these responses has the greatest impact, any negative interactions of concurrent strength and endurance exercises may be localized and therefore only affect the recruited muscles, or may be more widespread and thereby affect performance in other muscle groups.

The purpose of the present study was to investigate whether order of exercise (strength vs. endurance) acutely affected performance during a concurrent exercise regimen. A second purpose was to determine if such effects were localized to the muscles used or whether they were generalized to other muscle groups.

Methods

Subjects

Eighteen male college students volunteered to participate in this study. Subjects recruited had participated previously in both strength and endurance training programs. Subject characteristics are presented in Table B1 of Appendix B. All subjects volunteered after being informed of the potential risks and benefits of participation, as well as the procedures that would be followed. They then read and signed an informed consent form, an example of which can be found in Appendix C.

Design

Subjects were randomly assigned to one of two groups. Each group (n = 9) performed either upper body (UB) or lower body (LB) strength exercises and endurance exercise (i.e., cycling). All subjects visited the lab for two sessions to test the acute impact of concurrent exercise regimens. During their initial workout, half of the subjects in each of the two groups performed the strength protocol immediately followed by the endurance protocol (S/E). The time between exercise protocols was 6-10 minutes. After a period of at least one week but not more than two, subjects completed the second session with the order of exercise reversed by performing the endurance protocol immediately followed by the strength protocol (E/S). The remaining subjects in each group followed the same procedure, but performed E/S the first week followed by S/E the second week.

Pre-test Measurements

Prior to the two training session visits, peak O_2 consumption and muscular strength were assessed. This information allowed determination of workloads to be used during exercise sessions. These measures were made as follows:

Measurement of VO_2 peak. Peak O_2 consumption was measured during a standard graded exercise test on a Monarch cycle ergometer. The initial load was set at 50 watts and increased by 50 watts every 2 minutes. When the load was 200 watts, the increment was reduced from 50 watts to 25 watts every 2 minutes. Revolutions per minute (RPM) were also varied in a predetermined fashion. The specific protocol that was used is found in Appendix D. The test was terminated when the subject was unable to maintain pedal cadence within 10 RPM of the required rate. Expired gases were collected and analyzed using a computerized metabolic measurement system (SensorMedics 2900, Yorba Linda, CA), and oxygen consumption was determined every 20 seconds. Calibration was completed before each test using gases of known concentration. Heart rate was monitored continuously using an electronic heart rate monitor, and rating of perceived exertion (RPE) was recorded every 2 minutes.

Muscular strength. All weight training was performed on Universal equipment (Universal Inc., Cedar Rapids, IA). Five exercises were performed by each group to determine a reasonable exercise intensity for either the upper or lower body exercise routine. For each exercise, a warm-up set was performed after which the weight was adjusted to reflect an expected 10 repetition maximum (RM). The subjects performed repetitions to exhaustion at a three second cadence. If the number of repetitions did not fall within a range of 8 to 12, the weight was adjusted accordingly and a three minute rest period was given. This process was repeated no more than three times per exercise during which the 10 RM was determined for all subjects.

Endurance Exercise Protocol

The endurance exercise protocol involved riding a cycle ergometer (Jaeger, Rockford, IL) for 30 minutes.

The subjects rode at 50% VO_2 peak for the first five minutes. At this point and at five minute intervals thereafter, they were instructed to adjust the power output to reflect an RPE of 14 (between 'somewhat hard' and 'hard'). Endurance was measured as the average power output during the 30 minute ride. This was calculated by averaging the workloads used during the six five-minute intervals that comprised the entire ride. Heart rate was monitored continuously during the ride, and was recorded at the end of the first five minutes and every five minutes thereafter. These six values were used to determine the average heart rate for the ride.

Strength Exercise Protocol

The strength protocol involved three sets of a maximum number of repetitions using the weight determined from the pre-test strength measurement. Repetitions were performed at a three second cadence for each of five upper or lower body exercises. Each set was terminated when the cadence could not be maintained, and was followed by two minutes of rest. These commonly used exercises were performed in standard fashion and in the order given in Table B2 of Appendix B. The weight that was used for each strength exercise was held constant, so the number of repetitions that each subject performed was the only measured parameter of strength that could potentially vary between trials. Therefore strength was measured as the number of repetitions performed per set per exercise rather than as kg of force produced.

<u>Lactate Measurements</u>

Lactate levels were measured three times during the testing sessions: 1) preexercise (Resting), 2) after the first exercise protocol but before the second (Time 1), 3) after the second exercise protocol (Time 2). Resting lactate level was measured after the subject had been sitting quietly for five minutes. Exercise lactate levels (i.e., Time 1 and Time 2) were measured within 2-4 minutes following completion of the exercise protocol.

Blood samples were collected from a fingertip using a lancet and a 25 μl heparinized capillary tube. Samples were immediately injected into a lactate analyzer (YSI 1500, Yellow Springs, OH), and values were recorded.

<u>Statistical Analysis</u>

Data were analyzed using 2 X 2 (Group X Order) repeated measures analysis of variance (ANOVA) with the exception of lactate values, which were analyzed using a 2 X 2 X 3 (Group X Order X Time) ANOVA with two repeated measures. Post-hoc repeated measures t-tests were performed for significant ANOVA results. The level of significance was set at $p < 0.05$.

Results

The raw data are found in Appendix E. A summary of the results follows:

Muscular Strength

A significant interaction with post-hoc analysis indicated that the number of repetitions performed per set during the strength protocol decreased when preceded by endurance exercise (Appendix F, Tables F1 and F2). Further analysis revealed that only LB repetitions decreased (from 10.4 to 8.4) following the 30 minute cycle ride ($p < 0.002$). The number of repetitions performed by UB did not change with order of performance (Figure 1; Appendix F, Tables F3 and F4).

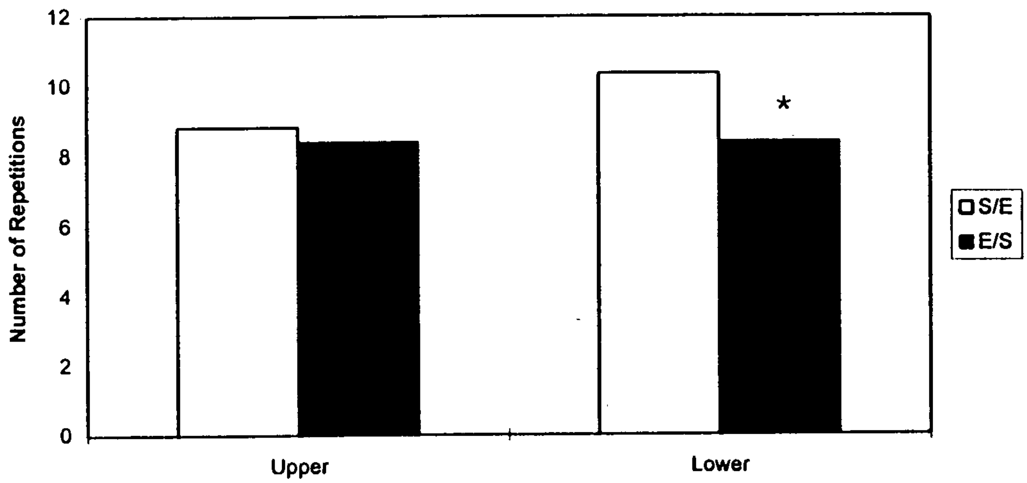

Figure 1. Number of repetitions performed by upper and lower body strength training groups prior to and following endurance training.

* p<.05 indicates significant difference between orders.

Endurance

There was no significant interaction between groups. However, a main effect was detected for exercise order. The average riding load chosen by the subjects decreased from 141.3 W to 132.7 W when the order changed from E/S to S/E (Appendix F, Tables F5 and F6). Therefore, regardless of whether upper or lower body exercise preceded cycling, performance in cycling was impaired.

Lactate

There were no significant differences between UB and LB lactate values. However, there was a significant interaction between order and time for blood lactate (Appendix F, Tables F7 and F8). Further analysis revealed that while order of performance did not impact lactate values at Resting, it did affect exercise lactate values at Time 1 and Time 2 (Figure 2; Appendix F, Tables F9-F11). This shows that the strength exercises elevated lactate values more than endurance protocol.

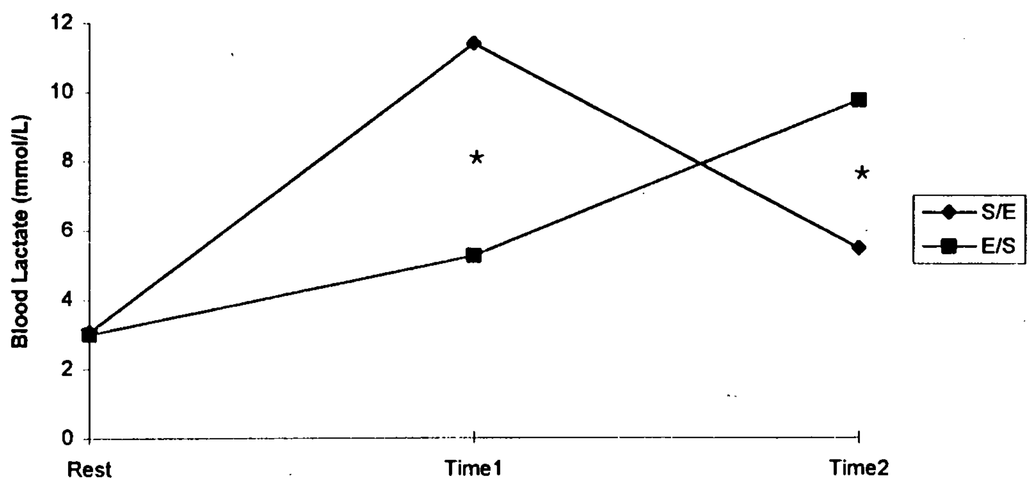

Figure 2. Changes in blood lactate values with time during a combined strength and endurance exercise session. Note: UB and LB group data have been combined.

* $p<.05$ indicates significant difference between orders at a given time.

Heart Rate

There were no differences in heart rate during endurance exercise regardless of order of exercise (Tables F12 and F13). There were also no differences in heart rate between LB and UB groups.

Discussion

In the present study, the number of repetitions that could be performed during a strength protocol decreased significantly when immediately preceded by endurance exercise. This impairment only appeared to affect the muscles that were used during the endurance activity because when cycle exercise was followed by an upper body strength workout, strength performance was not compromised. These acute results mirror the long-term changes reported by Hennessy et al. (1994) in which lower body strength was chronically compromised following a running protocol, whereas upper body strength was unaffected by prior lower body exercise. Both running and cycling primarily recruit leg muscles, so local muscle fatigue may have been a factor that caused smaller gains in lower body strength observed both chronically by Hennessy et al. and acutely in the present study.

Conversely, endurance performance was acutely compromised following strength exercise regardless of whether strength exercise involved the upper or the lower body. Although the absolute workload decreased during the endurance exercise that followed strength exercise, heart rate was unaffected by order of exercise performance. A previous investigation has shown that heart rate, RPE, and blood lactate values during cycle exercise were higher when strength exercise was performed prior to the cycle ride (Conlee, Fisher, & Allson, 1991). This was true for exercise at prescribed intensities of both 65% and 75% of VO_2 max. In the above study subjects cycled at the same absolute workload, whereas subjects in the present study cycled at the same relative level of exertion as determined by RPE.

Since endurance cycling performance was impaired by both upper and lower body strength exercises, it is unlikely that local muscle fatigue following the strength regimen was responsible. Instead the observed interference may be due to elevated levels of blood lactate that develop as a result of strength exercise. Blood lactate levels were almost four times above resting levels when strength exercise was performed, both for UB and LB groups. The elevated lactate levels following strength exercise could have increased carbon dioxide in the blood due to buffering. This would increase ventilation rate during subsequent endurance exercise, which could make performance of the cycle ride seem more difficult at a given workload. Thus, to maintain a specific RPE following strength exercise, subjects would be required to reduce their power output during the cycle ride. In contrast, lactate levels following endurance exercise did not increase nearly as much. With less lactate in the blood following endurance exercise as compared to strength exercise, there is less likelihood that increased blood lactate would be a mechanism for interference during subsequent strength exercise.

Previous studies have shown chronic impairments in performance following concurrent training over a period of weeks. Some of these investigations had subjects perform exercise on alternating days, thus eliminating much of the possibility that acute negative effects took place. For example, Dudley & Djamil (1985) found impairments in strength gains in subjects who performed both strength and endurance training on alternate days as compared to subjects who only strength trained.

However, other studies have had subjects perform the activities in immediate succession, as was done in the present study. Subjects who trained for both strength and endurance on the same day had smaller strength gains over a period of 20 weeks than subjects who trained for both strength and endurance on alternate days (Sale, Jacobs, MacDougall, & Garner, 1990). It may be possible that the second group would have had impaired strength gains when compared to a group that trained for strength only, but that information is not available. In addition to studies showing impaired gains in strength, Nelson et al. (1990) found that endurance gains were compromised over time when endurance training was immediately preceded by strength training.

The acute impairments that were observed during the present study could help to explain the chronic interference that has been observed in previous investigations. Attempting to train for strength immediately after an endurance exercise session may result in fewer repetitions performed if similar muscles are employed. Thus, less total force will be produced. If less work is done during the session, the body is not exposed to the same amount of overload and over time might potentially experience smaller gains than would be seen if the strength exercise were performed alone.

Similarly, endurance exercise at a specific RPE following a strength training session resulted in a lower power output. If gains in cardiovascular endurance with chronic training are dependent upon the absolute power that is produced during the exercise session, then these acute interactions may be important. It has been shown in previous studies that reductions in endurance training volume and/or intensity at best allow for maintenance of aerobic capacity and performance (Houmard, Costill, Mitchell, Park, Hickner, Roemmich, 1990; McConell, Costill, Widrick, Hickey, Tanaka, & Gastin, 1993). However, in these studies the volume of training was reduced by 70 percent, whereas in the present investigation the amount of work performed was reduced by only 6 percent. In addition, most studies of concurrent training have determined that strength training has no effect on gains in endurance. Thus, improvements in endurance may be more dependent upon maintaining heart rate in a specific target range. This might be accomplished by prescribing a specific RPE as was done in the present study.

Recent studies have questioned the reality of the interference effect. A study by Collins & Snow (1993) found that adaptations to strength and endurance training appeared to be independent of order of performance. Two groups performed either strength then endurance training, or visa versa. The only measure that was significantly different was shoulder press strength. McCarthy et al. (1995) also found no differences in strength or endurance gains in a combined group when compared to groups that trained exclusively for strength or endurance. The combined group alternated order of exercise with each training session, but performed both within 20 minutes of each other. Differences in results between studies can be attributed to different methodologies used. The endurance and strength protocols varied in frequency, intensity, duration, and mode of exercise. In addition, the order in which the two exercise sessions were performed and the time between the sessions varied between studies. All of these factors could play a role in the amount of interference.

The results of the present study and those of previous investigations suggest that interference may be attributed to both chronic and acute interactions between strength and endurance training. Muscular adaptations to endurance training over a period of time might attenuate gains in strength. In addition, acute interactions might cause impaired function in both strength and endurance performance within a single session. The subsequent reduction in training volume may play a part in chronic interference that is observed over time.

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APPENDIX A: REVIEW OF LITERATURE

INTRODUCTION

The goal of many exercise programs is to improve fitness level. Maximizing the rate of improvement would be ideal and exercise protocols are often manipulated in an attempt to achieve this goal. From experimentation, specificity of training has emerged as an important concept in the development of fitness. This theory holds that to develop muscular endurance, endurance activity (i.e. continuous high repetitions at a sub-maximal load for a prolonged time) specific to the muscle groups to be trained should be used while to develop muscular strength, resistive exercises (i.e. sets of low repetitions at maximal load) should be employed that are specific to the muscle groups to be trained (Fisher & Jensen, 1990, pp. 168-169).

When the desired result is to gain both muscular strength and endurance, it would seem reasonable to design a conditioning program that includes concurrent strength and endurance training components. However, physiological responses and adaptations of the two modes of training may conflict and lead to an interference effect. Thus, the improvements that would be observed if either mode of exercise was performed alone are potentially reduced due to interactions between them when executed together.

There has been some debate over the presence and the effect of the interference effect in training studies. This review will focus on the following areas: (a) rationale for the interference effect, (b) effects of concurrent training on strength performance, (c) effects of concurrent training on endurance performance, and (d) summary.

Rationale for the Interference Effect

The interference effect could be caused by any of a number of factors. Two specific factors that interference is currently attributed to include (a) chronic adaptations to exercise and (b) acute responses to exercise.

Chronic adaptations to exercise

Skeletal muscle undergoes chronic changes as a result of exercise. In many cases, the changes elicited by endurance training oppose those that would be brought about by resistance exercise. For example, endurance exercise may cause shifts in fiber type distribution from type IIb to type IIa. In addition, capillarization of the muscle tends to increase with endurance training as does mitochondrial content

(Miller, 1992, pp. 71-76). Metabolic adaptations include an increased reliance upon fats as a source of energy as well as an increased ability to store glycogen within the muscle cells (Miller, 1992, pp. 97-120).

In contrast, resistance exercise causes reduced muscle capillarization and decreased mitochondrial content (Miller, 1992, pp. 71-76). These occurrences are due to muscle hypertrophy, a phenomenon that greatly affects fast-twitch fibers. These are the fibers that are most heavily recruited in resistance activity. Metabolic adaptations to resistance exercise are not well described but unlike the shift toward fat metabolism that is seen with endurance training, it is likely that creatine phosphate becomes a primary source of energy (Abernethy, Jürimäe, Logan, Taylor, & Thayer, 1994).

The antagonistic effects of the adaptations to endurance and resistance exercise should be evident. Fiber adaptations to endurance activity cause a reduction in type IIb fibers that are crucial in the process of heavy resistance work. This may lead to a decrement in relative strength gains. In addition, the adaptations to the two forms of exercise diametrically oppose one another in terms of capillarization and mitochondrial density. The net result of these conflicting adaptations may be impaired performance in either activity in comparison to training with either type of exercise alone.

Acute responses to exercise

There are several possible mechanisms for acute negative interactions between the two forms of exercise. Glycogen depletion associated with training is one. A single bout of resistive exercise significantly lowers muscle glycogen stores (Miller, 1992). In addition, repeated bouts of exhaustive endurance activity are known to cause chronic glycogen depletion (Dudley & Fleck, 1987). Because both resistive exercise and endurance activity show some reliance upon muscle glycogen as a fuel source, reduction in glycogen levels following performance of one activity could negatively impact the amount of work performed in the other. For example, performing resistive exercise after endurance training with a diminished glycogen supply might limit the volume of work that could be done and ultimately have a negative impact on adaptations.

Studies have investigated the possibility of overtraining as a potential cause of decreased strength performance. This seems reasonable because a person training for both strength and endurance would potentially spend twice as much time exercising as a person training for one of the two. This would greatly increase the demands on the body and may increase need for recovery time. In a study of combined cycling and isokinetic strength training, the subjects involved were continuously monitored throughout the training program to assess whether overtraining had occurred (Nelson, Arnall, Loy, Silvester, & Conlee, 1990). Although no signs or symptoms of overtraining were observed in any of the subjects, maximal O_2 consumption in the combined training group plateaued after week 11 while it continued to increase in the endurance only group for the 20 weeks of the study.

In addition, muscle fiber fatigue could be a possible cause for acute negative interactions. If the muscles are already fatigued from one form of exercise then performance in the other may be impaired depending upon the amount of overlap in fiber recruitment between the two. This is more likely to occur when the endurance activity is performed at a higher intensity and when the resistive exercise involves more repetitions with less weight. Under these conditions more similar muscle fibers will be recruited by both processes.

Waste products and other metabolites that accumulate as a result of exercise in either program could hinder performance in the other program. For instance, heavy resistive work is known to cause lactic acid and catecholamine levels to rise (Miller, 1992). These may interfere with muscular function in subsequent endurance activity. Thus order of exercises and recovery time between modes of exercise may be potentially important considerations.

One study investigated the importance of order of concurrent training (Collins & Snow, 1993). One group performed strength training involving both the upper and lower body immediately followed by a running workout, while the other group performed the activities in the opposite order. After 7 weeks there were no significant differences in endurance or in any of the strength measures with the exception of shoulder press. The authors concluded that order of activity was not an important consideration for long term adaptations when combining strength and endurance training in a single session.

Effects of Concurrent Training on Strength Performance

Several studies have come to the conclusion that endurance training may negatively affect expected gains in strength. In a study using previously untrained subjects, strength gains were less for subjects performing concurrent strength and endurance conditioning than for subjects performing only strength exercises (Hickson, 1980). However, similar gains were observed in both groups until week seven. During the final three weeks the combination group plateaued and then declined in strength. The exercise protocols performed by the combination group were normally separated by at least two hours which suggests that chronic rather than acute responses to training were responsible for strength impairment.

Another study examined the effects of prior endurance conditioning on the development of strength during concurrent training (Hunter, Demment, & Miller, 1987). Previously endurance trained subjects who performed both strength and endurance exercise showed equal gains in strength when compared to untrained subjects who only strength trained during the study. In contrast, previously untrained subjects performing both strength and endurance exercise showed less gains in strength when compared to the strength only group. It therefore appears that initially less conditioned subjects are more likely to display the effects of interference.

Another study involving combined strength and endurance regimens found that gains in strength were less hindered in the upper body than in the lower body (Hennessy & Watson, 1994). In this experiment the endurance component of the exercise protocol was running, and included two low intensity and two high intensity runs per week. The strength component involved weight training of both the upper and lower body three days per week. Franklin (1989) also demonstrated that endurance training effects seem to have limited or no transfer between limbs. From the results of these two studies it appears that the amount of interference observed is related to the specificity of the muscles being exercised. Those muscles that have been specifically conditioned during the endurance activity exhibit lesser gains in strength than those that are not directly involved in the endurance activity.

The relationship between speed of contraction and amount of interference was investigated by Dudley &

Djamil (1985). They found that low-velocity, high-force contractions were not affected by combining strength and endurance activity, but that high-velocity, low-force contractions were inhibited. The strength training in the latter case more closely mimics the type of contractions that would be performed during endurance activity. This evidence supports the idea that the interference effect is velocity-specific, possibly due to patterns of fiber recruitment.

The effects of performing concurrent exercise on the same versus alternating days has also been investigated. One group trained for both strength and endurance on the same day, twice a week while another group trained for strength twice a week and for endurance twice a week on alternating days. The results revealed that while both groups increased in strength, strength gains were greater for the group that separated the training sessions (Sale, Jacobs, MacDougall, & Garner, 1990). The "same day" subjects alternated the modality of exercise performed first from one day to the next, so it is unclear whether the lesser improvement in strength was due to interference because of fatigue from the endurance activity or to chronic adaptations to the endurance training.

However, the latter is unlikely because the other group would have experienced those adaptations as well.

Another study investigated the effect of interference using an intrasubject methodology (Sale, MacDougall, Jacobs, & Garner, 1990). Half of the subjects trained both legs for strength and one leg for endurance. The other subjects trained both legs for endurance and one leg for strength. Both strength and endurance training were performed on the same day, and endurance training always preceded strength training. The results showed no impairment of performance when comparing combination trained legs to endurance-only or strength-only trained legs. This could be due to the exercise protocols used. The strength training regimen was 6 sets of 15-20 repetitions at moderate resistance with 2 minutes rest between sets. The endurance training regimen was 5 sets of 3 minute repetitions on a cycle ergometer at a high resistance of 90-100% VO_{2max}. These protocols are atypical of those followed by previously mentioned studies in that the two modes of exercise are more similar to one another and are therefore less likely to result in interference.

A more recent study of combined training found comparable gains in strength between subjects who trained for only strength and those who combined both strength and endurance training (McCarthy, Agre, Graf, Pozniak, & Vailas, 1995). The gains were equivalent for both upper and lower body strength measures, namely 1 RM for bench press and squat, as well as vertical leap. The endurance protocol involved riding a cycle ergometer for 45 min. at 70% of heart rate reserve, while the strength protocol consisted of three maximal effort sets of eight exercises with a goal of attaining six repetitions per set. The two protocols were separated by a rest period of 10-20 min. and were reversed after every session. Training sessions were performed three times a week.

Effects of Concurrent Training on Endurance Performance

The results of studies examining the effects of combining strength and endurance exercise regimens on endurance performance have mainly concluded that endurance performance is not significantly affected by concurrent conditioning (Dudley & Djamil, 1985; Hickson, 1980; Sale, Jacobs, MacDougall, & Garner, 1990; Sale, MacDougall, Jacobs, & Garner, 1990). However, a study of subjects on a maintenance endurance exercise program who started a strength training program showed an increase in short-term endurance (measured by time to exhaustion at a workload designed to cause total fatigue within 5-8 minutes) (Hickson, Dvorak, Gorostiaga, Kurowski, & Foster, 1987). There was, however, no increase in VO_{2max}. The improvement in short-term endurance performance was attributed to the fact that this type of activity would recruit more fast-twitch fibers. These are the same fibers that would be trained with resistance activity.

Another study suggested that combined training could negatively impact endurance performance. Subjects who performed both endurance and strength protocols had similar gains in both strength and endurance when compared to single protocol subjects for the first 11 weeks of the study. However, the endurance performance of the combination group showed no further improvement whereas the endurance performance of the endurance-only group continued to increase throughout the investigation (Nelson et al., 1990). This study was conducted over a longer period and/or included a higher volume of training than the studies that showed no significant interference effect upon endurance performance. Thus the participants may have experienced overtraining, which could impair endurance performance.

Summary

The results of the few studies that have investigated the interaction between concurrent strength and endurance exercise regimens suggest an interference with expected strength gains and little or no effect on endurance performance. The mechanisms for these results at this point are unclear. However, chronic adaptations and acute responses of skeletal muscle to exercise are the two most commonly proposed mechanisms for the interference effect. The chronic adaptations may include changes in muscle fiber type distribution, muscle capillarization, mitochondrial content, and shifts in substrate use. Acute responses that might account for interference include glycogen depletion, muscle fiber fatigue, and accumulation of waste products.

There are several factors that need to be considered in the investigation of interference between strength and endurance training. The initial level of fitness appears to be an important factor in the amount of interference observed, with previously endurance trained subjects experiencing less of an inhibitory effect on strength gains. Additionally, the speed of contraction during strength training is important, with higher velocity contractions leading to a larger observed interference effect. The time between performance of strength and endurance activity appears to be an important variable, with greater time leading to less interference. The importance of order of the exercises performed, however, is still unclear.

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APPENDIX B: METHODS TABLES

Table B1

Subject Characteristics

Age (yrs)	Height (cm)	Weight (kg)	Peak VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)
22.4 ± 4.2	181.1 ± 6.9	92.3 ± 17.0	44.9 ± 5.9

(n=18)

Table B2

Strength Exercises

Upper Body	Lower Body
Bench Press	Squat
Lat pull down	Leg Press
Military Press	Leg Extension
Biceps Curl	Leg Curl
Triceps Press	Calf Raises

APPENDIX C: INFORMED CONSENT FORM

Concurrent Strength/Endurance Exercise Study

1. <u>Purpose of the Study</u>

This study will assess the effects of exercise order and the specific muscles recruited on concurrent performance of strength and endurance activities.

2. <u>Benefits of the Study</u>

The results of this study may reveal methods of optimizing gains with concurrent strength and endurance exercises, along with expanding the base of knowledge about muscle function.

3. <u>What You Will Be Asked to Do</u>

You will be asked to perform in 3 exercise sessions. The first session will assess your initial strength and endurance, and the data collected will be used as information in the second and third sessions. In the second and third sessions, you will be asked to perform a strength training and endurance training protocol to exhaustion. The order of the two types of exercise will be reversed between sessions. Each session will last about 90 minutes, and at least 1 week will separate sessions. During these two sessions, three small samples of blood will be collected from a fingertip for lactate analysis.

4. What You Can Expect to Happen as a Result of Your Participation

There is some physical risk associated with this study. Muscle soreness, strains, and other injuries associated with intense physical activity could result from participation, especially if you do not participate regularly in exercise. To minimize these risks, proper technique for each exercise will be demonstrated and an appropriate warmup and cooldown period will be utilized. If muscle soreness persists for more than one week, you should contact the health center (274-3177). If you have a personal history of health problems or are restricted from participation in vigorous physical activity, you should not volunteer for this study.

5. If You Would Like More Information About the Study

To obtain results or further information about the study, please contact

Craig Todd or Dr. G. A. Sforzo
1287 Old DeKalb Rd. (607) 274-3359
Canton, NY 13617
(607) 275-2735 or (315) 386-4013

6. <u>Withdrawal from the Study</u>

Your participation in this study is purely voluntary and you may withdraw at any time you choose if you participate.

7. <u>How the Data Will be Maintained in Confidence</u>

Because you will be tested on 3 separate occasions, it will be necessary to identify the data with an identification number for collating purposes. Following the completion of data collection, all information will be maintained confidentially.

I have read the above and I understand its contents. I agree to participate in the study. I acknowledge that I am 18 years of age or older.

____

Print or Type Name ___________________________

____

Signature   Date

APPENDIX D: PROTOCOL FOR MEASURING VO_2 PEAK

Stage	Min	Load (W)	rpm	Resistance (kp)
1	1	50	60	.83
	2			
2	3	100	70	1.43
	4			
3	5	150	80	1.88
	6			
4	7	200	90	2.22
	8			
5	9	225	90	2.50
	10			
6	11	250	90	2.78
	12			
7	13	275	90	3.06
	14			
8	15	300	90	3.33
	16			
9	17	325	90	3.61
	18			
10	19	350	90	3.89
	20			

APPENDIX E: RAW DATA

Note. E/S = order of endurance followed by strength. S/E = order of strength followed by endurance. Upper = group that performed upper body strength exercises. Lower = group that performed lower body strength exercises. Resting = Blood lactate value before either exercise session was performed. Time 1 = Blood lactate value between the two exercise sessions. Time 2 = Blood lactate value after both exercise sessions were performed. HR = Heart Rate (beats/min).

RAW DATA (cont'd)

Subject	Group	E/S Reps	S/E Reps	E/S Power (Watts)	S/E Power (Watts)
1	lower	8.8	11.8	125.8	121.7
2	lower	8.5	12.2	150.8	143.3
3	lower	10.3	10.1	124.2	110.8
4	lower	7.7	8.9	174.2	174.2
5	lower	7.2	8.4	100.8	92.5
6	lower	11.7	12.2	168.3	111.7
7	lower	6.7	10.7	150.0	145.8
8	lower	7.7	9.6	153.3	146.7
9	lower	7.1	9.5	75.0	78.3
10	upper	6.5	6.4	140.0	134.2
11	upper	10.9	10.1	145.0	135.0
12	upper	6.2	7.5	144.2	148.3
13	upper	9.8	9.5	157.5	133.3
14	upper	8.3	8.7	167.5	165.0
15	upper	7.5	8.2	134.2	133.3
16	upper	9.7	10.0	126.7	129.2
17	upper	9.5	10.0	159.2	159.2
18	upper	7.3	9.1	147.5	126.7

RAW DATA (cont'd)

Subj	Group	E/S Rest (mmol/L)	S/E Rest (mmol/L)	E/S Time 1 (mmol/L)	S/E Time 1 (mmol/L)
1	lower	3.55	2.78	3.45	8.53
2	lower	2.24	4.01	5.58	14.35
3	lower	2.50	2.48	4.73	7.96
4	lower	1.66	2.26	7.04	8.53
5	lower	2.36	1.73	2.38	4.98
6	lower	3.18	1.15	8.01	11.22
7	lower	2.28	4.46	3.91	16.17
8	lower	1.34	2.44	4.82	9.59
9	lower	3.20	2.51	4.26	13.12
10	upper	2.53	3.11	8.33	8.42
11	upper	2.79	4.37	4.20	16.98
12	upper	2.06	4.79	2.97	19.27
13	upper	1.56	1.87	2.69	10.28
14	upper	2.81	1.80	8.69	13.34
15	upper	8.99	3.84	2.54	10.86
16	upper	2.54	3.19	3.24	8.72
17	upper	3.11	3.13	6.17	10.27
18	upper	5.28	5.22	11.29	12.01

RAW DATA (cont'd)

Subject	Group	E/S Time 2 (mmol/L)	S/E Time 2 (mmol/L)	E/S HR (b/min)	S/E HR (b/min)
1	lower	6.78	2.29	142.5	138.0
2	lower	6.96	7.90	143.7	135.8
3	lower	9.65	4.05	154.2	168.0
4	lower	9.80	5.93	166.8	170.7
5	lower	3.18	2.70	148.5	141.2
6	lower	11.83	5.90	150.5	130.0
7	lower	9.23	6.53	162.8	162.2
8	lower	7.23	3.04	161.2	167.5
9	lower	11.35	4.87	124.7	134.7
10	upper	10.01	7.03	155.2	165.7
11	upper	10.74	5.23	128.3	140.3
12	upper	6.88	6.10	159.2	150.8
13	upper	10.12	3.17	139.2	132.2
14	upper	15.76	6.11	138.0	145.2
15	upper	8.16	3.52	133.0	140.8
16	upper	12.81	3.32	115.2	127.3
17	upper	10.63	8.14	158.2	164.5
18	upper	13.82	12.35	179.5	172.7

RAW DATA (cont'd)

Subject	Group	Peak VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	Height (cm)	Weight (kg)	Age (yrs)
1	lower	49.08	180	74.1	35
2	lower	34.57	188	126.4	21
3	lower	45.67	173	83.2	20
4	lower	44.60	180	102.7	21
5	lower	48.50	168	68.2	24
6	lower	41.40	198	122.3	20
7	lower	40.00	183	110.9	21
8	lower	55.90	178	74.5	21
9	lower	35.30	183	82.3	21
10	upper	42.88	178	81.4	23
11	upper	43.27	183	95.5	20
12	upper	39.96	173	94.1	21
13	upper	44.62	185	99.5	22
14	upper	53.30	185	86.4	30
15	upper	41.10	183	107.3	19
16	upper	52.90	183	78.6	26
17	upper	44.10	175	100.0	18
18	upper	50.70	183	74.1	20

APPENDIX F: STATISTICAL ANALYSIS

Table F1

2X2 ANOVA (Groups X Order) on Repetitions Performed During the Strength Protocol

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj	67.162	17			
Groups	5.367	1	5.367	1.390	.2557
Error	61.796	16	3.862		
Within Subj.	28.945	18			
Treatments	12.840	1	12.840	19.133	0.0005
Interaction	5.367	1	5.367	7.997	0.0121
Error	10.738	16	0.671		
Total	96.107	35			

Table F2

Number of Repetitions Performed During the Strength Protocol

		Mean	Std. Dev.
Measure	E/S Reps	8.411	1.595
	S/E Reps	9.606	1.534
Group	Upper	8.622	1.442
	Lower	9.394	1.805
Upper	E/S Reps	8.411	1.643
Upper	S/E Reps	8.833	1.273
Lower	E/S Reps	8.411	1.646
Lower	S/E Reps	10.378	1.428

Note. See note for Appendix E.

Table F3

T-Test on Number of Repetitions Performed in Each Order for the Lower Body Group

Item	E/S Reps	S/E Reps
N	9	9
Mean	8.411	10.378
Std. Dev.	1.646	1.428
Difference in Means	1.967	
t-Value	4.118	
Probability One-tailed	0.0017	

Note. See note for Appendix E.

Table F4

T-Test on Number of Repetitions Performed in Each Order for the Upper Body Group

Item	E/S Reps	S/E Reps
N	9	9
Mean	8.411	8.833
Std. Dev.	1.643	1.273
Difference in Means	0.422	
t-Value	1.593	
Probability One-tailed	0.0749	

Note. See note for Appendix E.

Table F5

2X2 ANOVA (Groups X Order) on Power Output During the Endurance Protocol

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj	18427.385	17			
Groups	1581.387	1	1581.387	1.502	0.2381
Error	16845.998	16	1052.875		
Within Subj.	2389.596	18			
Treatments	667.361	1	667.361	6.363	0.0226
Interaction	44.001	1	44.001	0.419	0.5264
Error	1678.234	16	104.890		
Total	20816.981	35			

Table F6

Average Power Output Produced during the Endurance Protocol

		Mean (Watts)	Std. Dev.
Measure	E/S Power	141.344	24.597
	S/E Power	132.733	24.089
Group	Upper	143.667	13.294
	Lower	130.411	30.902
Upper	E/S Power	146.867	12.827
Upper	S/E Power	140.467	13.705
Lower	E/S Power	135.822	32.442
Lower	S/E Power	125.000	30.178

Note. See note for Appendix E.

Table F7

2X2X3 ANOVA (Groups X Order X Time) for Blood Lactate Levels

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj	245.8400	17	14.4612		
Groups	46.5862	1	49.5862	4.0426	
Subj w.gr	196.2538	16	12.2659		
Within Subj	1503.6161	90	16.7068		
Order	11.1490	1	11.1490	1.5032	0.2379
Groups.Ord	0.0984	1	0.0984	0.0133	0.9097
Ord x Subj	118.6692	16	7.4168		
Time	588.6765	2	294.3382	65.5538	0.0001
Groups.Time	4.7263	2	2.3632	0.5263	0.5958
Time x Subj	143.6808	32	4.4900		
Order.Time	490.5047	2	245.2524	56.0545	0.0001
Grp.Ord.Time	6.1033	2	3.0517	0.6975	0.5052
O x T x S	140.0080	32	4.3752		
Total	1749.4562	107			

Note. O x T x S = Order x Time x Subjects within groups.

Table F8

Blood Lactate Levels (mmol/L) Under Various Conditions of Time and Order

Measure	Upper	Lower
E/S Resting	3.5189	2.4789
E/S Time 1	5.5689	4.9089
E/S Time 2	10.9922	8.4456
S/E Resting	3.4800	2.6467
S/E Time 1	12.2389	10.4944
S/E Time 2	6.1078	4.8011
E/S	6.6933	5.2778
S/E	7.2756	5.9807
Resting	3.4994	2.5628
Time 1	8.9039	7.7017
Time 2	8.5500	6.6233
Overall Mean	6.9844	5.6293

Note. See note for Appendix E.

Table F9

T-Test on Resting Blood Lactate at Time 1 in Each Order of Performance

Item	E/S Resting	S/E Resting
N	18	18
Mean	2.9989	3.0633
Std. Dev.	1.7362	1.1640
Difference in Means		0.0644
t-Value		0.1544
Probability One-tailed		0.4396

Note. See note for Appendix E.

Table F10

T-Test on Blood Lactate at Time 1 in Each Order of Performance

Item	E/S Time 1	S/E Time 1
N	18	18
Mean	5.2389	11.3667
Std. Dev.	2.5266	3.6244
Difference in Means	6.1278	
t-Value	5.8746	
Probability One-tailed	0.0001	

Note. See note for Appendix E.

Table F11

T-Test on Blood Lactate at Time 2 in Each Order of Performance

Item	E/S Time 2	S/E Time 2
N	18	18
Mean	9.7189	5.4544
Std. Dev.	2.9510	2.4848
Difference in Means		-4.2644
t-Value		-6.2273
Probability One-tailed		0.0001

Note. See note for Appendix E.

Table F12

2X2 ANOVA (Groups X Order) for Heart Rate During the Endurance Protocol

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj	7994.8115	17			
Groups	92.4803	1	92.4803	0.1872	0.6710
Error	7902.3315	16	493.8957		
Within Subj.	809.3275	18			
Treatments	20.1901	1	20.1901	0.4344	0.5192
Interaction	45.4276	1	45.4276	0.9773	0.3376
Error	743.7098	16	46.4819		
Total	8804.1387	35			

Table F13

Heart Rate During the Endurance Protocol

		Mean (b/min)	Std. Dev.
Measure	E/S Heart Rate	147.8150	16.3111
	S/E Heart Rate	149.3128	15.8320
Group	Upper	146.9611	17.3603
	Lower	150.1667	14.5414
Upper	E/S Heart Rate	145.0889	19.5693
Upper	S/E Heart Rate	148.8333	15.7854
Lower	E/S Heart Rate	150.5411	12.8716
Lower	S/E Heart Rate	149.7922	16.8208

Note. See note for Appendix E.