AN ABSTRACT OF THE THESIS OF

Jason D. Wallis for the degree of Master of Science in Human Performance presented on July 19, 1994.

Title: Acute Effects of Strength Training on Cardiorespiratory Parameters During Subsequent Aerobic Exercise

Redacted for Privacy

Abstract approved: ____________________
Dr. Anthony Wilcox

The purpose of this investigation was to determine the acute effects of strength training on various cardiovascular, ventilatory, and metabolic parameters during subsequent aerobic exercise. Six fitness enthusiasts, previously trained in weightlifting (WL) and cardiovascular conditioning, performed a weightlifting session consisting of three Universal equipment leg exercises (leg press, leg extension, leg curl). Immediately afterward, the subjects exercised on a cycle ergometer at 65% of their $\dot{V}$O2max for 30 minutes. Physiological parameters of heart rate (HR), oxygen consumption ($\dot{V}$O2), ventilation ($\dot{V}$e), respiratory exchange ratio (RER), and rating of perceived exertion (RPE) were measured during submaximal trials and compared to controls who performed cycle ergometry without a previous strength training session.

An unpaired t-Test was employed to evaluate the influence of strength training on the various physiological parameters during submaximal aerobic exercise. Only heart rate changed significantly ($p < .05$) due to the intervention, whereas $\dot{V}$O2, $\dot{V}$e, RER, and RPE

were unaffected by the strength training session. The mean difference between submaximal exercise trials for heart rate within the control group was -1.0 beats per minute, whereas the experimental group showed an increase of 8.83 bpm between trials ($p = .0475$). Therefore, if fitness enthusiasts are judging exercise intensity by HR alone, they will achieve a lesser training stimulus during the aerobic conditioning phase of cross-training. Those judging exercise intensity by a predetermined equipment setting will achieve a higher HR but probably not a greater training stimulus.

Acute Effects of Strength Training on Cardiorespiratory Parameters During Subsequent Aerobic Exercise

by

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A Thesis

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed July 19, 1994

Commencement June, 1995

Master of Science thesis of Jason D. Wallis presented on July 19, 1994

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Jason D. Wallis, Author

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation and gratitude to my major professor, Dr. Anthony Wilcox for his ongoing advice and guidance throughout the course of this research project and my graduate studies. His sincere words of encouragement and genuine attention to the needs and interests of all students is hard to come by these days. I would also like to thank Dr. Terry Wood for his statistical expertise. His patience and understanding of a subject that is often a roadblock in this process is invaluable to many students. I would like to extend my appreciation to Dr. Ray Tricker who kindly and graciously filled in as an important committee member.

Special thanks are due to my housemate and pal, Jane LaRiviere, who made my life away from school comfortable and enjoyable and Susan Fox, whose knowledge, enthusiasm, and friendliness made the numerous testing hours in the Human Performance Lab worthwhile.

Last, and most importantly, I would like to thank my parents whose love, support, and encouragement have given me more confidence than anyone needs. I can't wait to repay you somehow.

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CHAPTER I

INTRODUCTION

Many athletic events and activities of daily living require a high degree of strength and endurance for optimal performance. Therefore, many of today's fitness enthusiasts and recreational athletes are interested in using simultaneous strength and endurance training in their pursuit of increased health and athletic success.

The primary goal of endurance-type training is improving cardiorespiratory functioning. Aerobic conditioning leads to better oxygen uptake efficiency through increases in mitochondrial density, citric acid enzyme activity, and oxidative capacity (Edgerton, 1978; Gollnick, 1973; Holloszy & Coyle, 1984). A well-developed aerobic system will enhance the body's ability to recover from high-intensity work by oxidation of lactate within muscle, removing waste products, and replenishing depleted high-energy phosphates (Bell, Arthur, & Wenger, 1988).

In contrast, the goal of resistance training is to increase muscular strength and, perhaps, size. A high-degree of strength can enhance the development of force during demanding interval work, help in the prevention of injuries, and provide added power for many sporting activities.

The nature of exercise adaptation appears to be specific to the training modality. The idea of total fitness frequently translates into an exercise program which places emphasis on both cardiovascular endurance and physical strength.

Cross-training programs, utilizing different modes of training to achieve total fitness, have been shown to increase both strength and endurance (Bell et al., 1988; Nelson, Arnall, Loy, Silvester, & Conlee, 1990; Sale, Jacobs, MacDougall, & Garner, 1990), but there seems to be uncertainty about the proper sequencing of such training. Many competitive athletes employ a regimen of five to six workouts each week, alternating weight training and aerobic conditioning, in an attempt to produce the greatest performance results. However, many exercisers in the fitness-wellness setting or in a recreational athletic program only exercise three or four times a week, prefering to combine strength training and aerobic activities within the same session.

Since the adaptive responses to weightlifting and aerobic conditioning are different and sometimes antagonistic, it is possible that skeletal muscle cannot adapt optimally to the two antagonistic training impulses when they are concurrently imposed. If this is the case, the order of exercise to achieve maximal strength and cardiovascular benefits is of particular importance to these individuals.

Long-term ramifications of combined strength and endurance training have been well documented (Bell et al., 1988; Nelson et al., 1990; Sale et al., 1990). Some clinicians, trainers, and athletes believe that cross-training to increase muscular strength and aerobic conditioning may be counterproductive. Some studies (Dudley & Djamil, 1985; Hunter, Diment, & Miller, 1987) have found no compromise in maximal oxygen consumption with concurrent endurance and resistance training. Hickson (1980) reported an "interference effect" that restricted the development of strength when endurance training was performed concurrently with heavy-resistance training. This research suggests that simultaneous endurance and resistance training may be limiting gains in each. Other findings (Baldwin et al., 1977 and Reidy, Moore, & Gollnick, 1980) suggest completing a weightlifting training phase prior to an aerobic conditioning phase over a period of time, or vice versa, may be an alternative to simultaneously training for both during the same phase.

Much of the current research has dealt with the long-term adaptive changes of resistance and endurance training, but the acute responses of strict sequencing have received little attention in the exercise and sports science literature. There remain unresolved questions in the area of evaluating the acute interrelationships between strength training and endurance work during the same exercise session. Weightlifting may cause fatigue during the first stage of the workout which may limit the ability to achieve normal responses during the aerobic stage. Sale et al. (1990) reported that the intensity and workloads of same-day concurrent training was diminished on days when strength training preceeded the aerobic activity. This is to say that the quality of the workout was diminished. It was hypothesized that this may be due to the subjects' anticipation of the difficult endurance training to follow. Fatigue or anticipation may have reduced the effort applied in the strength training or reduced the amount of weight lifted or the number of repetitions completed (Sale et al., 1990). There seems to be little, if any, information available investigating the acute aerobic response following a bout of maximal strength exercises in trained individuals.

Maintenance of healthy fitness levels in a time-efficient manner, rather than progressive periodization, is the aim of most recreational fitness participants. Therefore, a training program consisting of same-day, same-session endurance and strength training exercises is commonly employed. The ability of an individual to perform proper levels of aerobic conditioning after intense weightlifting is a key aspect of many exercise programs. Exercise and fitness specialists at health clubs, corporate fitness programs, and sports medicine clinics must understand the acute effects of a strength training session on an immediately following endurance session.

The rationale for this study is based on the achievement of specific physiological changes at a particular exercise intensity. This is the aim of many fitness enthusiasts who calculate a target heart rate for a specific submaximal level, expecting a certain feeling of exertion, and desiring the utilization of a particular energy substrate (fat, in most cases). Submaximal exercise at a given percentage of $\dot{V}O2max$ should elicit similar heart rate (HR), oxygen consumption ($\dot{V}O2$), ventilation ($\dot{V}e$), respiratory exchange ratio (RER), and rating of perceived exertion (RPE) measurements from one day to the next when an endurance-only exercise session is performed. An individual aerobic exercise intensity can be determined for the purposes of maintaining or slowly increasing cardiorespiratory capacity. As mentioned above, however, many exercise enthusiasts perform same-session strength and endurance training. This study is concerned with the acute physiological compromises which may occur after heavy resistance work. If the parameters of HR, $\dot{V}O2$, $\dot{V}E$, and RPE are increased during aerobic conditioning at a given intensity due to a strength training session, adjustments will need to be made in order to achieve the desired physiological responses. Furthermore, a decrease in RER during aerobic work immediately after weightlifting may be an indication of higher fat utilization. This would have significant implications in the area of health and fitness, particularly for those interested in fat loss. It may become evident that the capacity of an individual to perform a given amount of work is less after intense weightlifting. This change in ability may be psychological as well as physiological.

Statement of the Problem

The purpose of this study is to determine the acute physiological effects of a maximal strength training session on various metabolic and cardiovascular parameters during subsequent aerobic work in trained college-age male and female fitness enthusiasts.

Research Hypotheses

A review of the relevant literature leads to the hypotheses that a maximal bout of resistance exercise will:

a) increase heart rate, oxygen consumption, ventilation, and the rating of perceived exertion during subsequent submaximal aerobic exercise, as compared to the same responses when no previous resistance exercise has been performed.

b) decrease respiratory exchange ratio compared to non-sequenced aerobic exercise.

Statistical Hypotheses

The statisical hypotheses state that a) mean values of heart rate (HR), oxygen consumption ($\dot{V}O2$), ventilation ($\dot{V}e$), and rating of percieved exertion (RPE) during submaximal aerobic work will be higher after a strength training (ST) session compared to those measured without prior ST, and b) respiratory exchange ratio (RER) will be lower following ST.

a) H_0: $u_o \leqslant u_n$ b) H_0: $u_x \geqslant u_y$

H_1: $u_o > u_n$ H_1: $u_x < u_y$

where: o = HR, $\dot{V}O2$, $\dot{V}e$, and RPE values after ST

n = parameter values without previous ST

x = RER after ST

y = RER with no prior ST

Operational Definitions

The dependent and independent variables in this study will be measured in the following manner:

Aerobic power: $\dot{V}O2max$ determined via open circuit spirometry using a standard progressive exercise protocol on a Sensormedic cycle ergometer.

Strength training intensity: three sets of each resistance exercise performed at 100% of 8RM (the maximal amount of weight that can be lifted eight times on a Universal Gym weight machine.

Submaximal aerobic intensity: a predetermined (65% of $\dot{V}O2max$) steady state exercise on a Sensormedic cycle ergometer.

Heart rate: monitored continuously by a Sensormedics MAX-1 electrocardiograph unit using a V5 lead arrangement.

$\dot{V}O2$: oxygen consumption (L/min).

$\dot{V}e$: rate of ventilation (L/min).

RER: respiratory exchange ratio. Indicates amount of carbohydrate and fat utilization as energy substrates.

$\dot{V}O2$, $\dot{V}e$, and RER: measured by a Sensormedic 2900 metabolic cart analysis system.

RPE: rating of perceived exertion. Feeling of exercise stress or intensity based on physiological cues. Indicated by subject using a standard Borg Rating of Perceived Exertion Scale.

Assumptions

For the puposes of this study the following will be assumed:

1. Subjects will put forth their maximal effort at all times during the weightlifting activity and the maximal cycle ergometer test.
2. Each subject will follow all procedural guidelines for warm-up, weightlifting, and cycle activities for all testing periods.
3. Subjects will not significantly alter their individual training programs between testing sessions.
4. All subjects will be in good health throughout the testing period.
5. Nutritional and rest habits will remain constant for each subject throughout the duration of the study.

Delimitations

This study will be delimited to college-age individuals who have had previous experience with strength and endurance training. Results from this investigation may be generalized to weightlifting exercises involving the legs and to steady-state cycle ergometry. Only acute responses will be evaluated.

Limitations

The following will be considered limitations in the study:

1. Subjects will be aware that they are taking part in a research project.
2. Because all subjects will have access to training facilities, additional exercise cannot be controlled.
3. Subject diet or eating habits cannot be controlled, nor can the amount of daily rest.
4. Subject motivation may change throughout the testing period.
5. All testing was performed by the principle investigator (experimental effects).
6. Small sample size may result in low statistical power leading to alternative interpretation of non-significant statistical tests.

CHAPTER II
LITERATURE REVIEW

This literature review investigates the physiological changes which may occur during an exercise session designed to increase both muscular strength and physical endurance. Little information exists regarding the acute responses to concurrent training programs. Much of the reviewed research deals with long-term adaptations to simultaneous strength and endurance training. Attention is paid to the possible mechanisms by which the adaptations occur. Physiological mechanisms which may cause changes in various measured parameters are also discussed. These include energy substrate utilization, metabolic by-products, overwork, and psychological effects of cross-training. Finally, methodological differences in exercise research are examined.

Adaptive Changes to Strength and Endurance Training

Athletes and fitness enthusiasts training for high-intensity, short-duration activities usually incorporate weightlifting in their training for enhanced performance. These individuals may also incorporate aerobic development in their workout regimen in order to maintain a high cardiovascular capacity. One question to be answered is whether concurrent training compromises or promotes endurance training. Three possible scenarios exist. When strength and endurance training are practiced simultaneously, they may not interact at all. That is to say, concurrent training would result in the same training effect as strength or endurance training carried out alone. Combined training may have an antagonistic effect. Strength and/or endurance adaptations may be less than those seen with strength or endurance training alone. Lastly, a cross-training program may cause enhancement to strength and endurance capabilities. The possible additive effect would be greater than that due to training for strength and endurance separately.

Hickson (1980) and Dudley and Djamil (1985) studied the compatibility of concurrent strength and endurance training programs. The strength-trained subjects in Hickson's longitudinal study performed resistive training 5 days/week for 10 weeks. Three days/week they performed parallel squats (5 sets of 5 repetitions) and knee flexions and knee extensions (3 sets of 5 repetitions each). Two days/week they performed leg presses (3 sets of 5 reps) and calf raises (3 sets of 20 reps). All exercises were performed using the maximal workload possible for the required number of repetitions. The endurance group trained 6 days/week for 10 weeks. Three days/week these subjects engaged in interval-training on a cycle ergometer which consisted of 6 5-minute work bouts at a rate which approached the subject's $\dot{V}O2$ max. On alternate days, subjects participated in a running program. They ran as fast as possible for 30 minutes during the first week, 35 minutes the second week, and 40 minutes during weeks 3 through 10. The subjects in the combination strength and endurance group performed the same exercise regimen as the strength-only and endurance-only groups, engaging in endurance training 6 days/week and strength training 5 days/week. These same-day training sessions were typically separated by at least two hours of inactivity. Following 10 weeks of training, $\dot{V}O2max$ increased 25% during cycle exercise and 20% when measured during treadmill exercise in both endurance and strength- and endurance-only groups. No increase in $\dot{V}O2max$ was seen in the strength-only group. Leg strength was consistently developed in the strength group throughout the training, whereas the endurance group did not show any significant gains in strength. These findings demonstrate that concurrent strength and endurance training will result in a reduced capacity to increase strength, but will not affect the magnitude of increase in $\dot{V}O2max$. Strength increments leveled off in the combination group after the eighth week and decreased over the last two weeks of training. The evidence from this investigation shows that simultaneous training resulted in increased aerobic power as well as muscle strength, but compromised strength development compared to strength training only. Weight training alone increased strength but had no effect on aerobic capacities. Likewise, endurance training only did not increase muscular strength. Overtraining can be described as training stresses too great to result in positive training adaptations because of physical and/or mental fatigue. Overtraining, using a simultaneous program, may have caused the limited increases in muscular strength but did not compromise aerobic power.

The results of Dudley and Djamil (1985) are similar to those of Hickson (1980), although the study design varied somewhat. Dudley and Djamil cut the number of training workouts in half and the total training time per week was reduced 75% relative to the measures used by Hickson (1980). Furthermore, they did not require performance of both modes of training on the same day. Strength training was performed on an isokinetic loading dynamometer 3 times/week for 7 weeks. Two sets of thirty seconds of maximal knee extensions were performed in each training sesssion. The endurance training was performed on a cycle ergometer 3 days/week also for 7 weeks. Five-minute exercise bouts with a 5-minute rest between bouts comprised a training session. Power outputs were chosen to elicit $\dot{V}O2$ max during the fourth and fifth minutes of each bout. The concurrent training group engaged in the same training programs as both of the other groups. They trained 6 days/week, alternating strength and endurance training on a daily basis. While slightly different in design, this study reports similar findings of concurrent training as Hickson's (1980) investigation. In both of the studies described above, it was paramount that the exercises eliciting changes in aerobic power and muscular strength involve the same major muscle groups.

In the above studies, simultaneous training in both modes of exercise did not decrease the peak $\dot{V}O2$ induced by endurance training only. Nelson et al. (1990) indicated, however, that simultaneous training for torque production and endurance may inhibit gains in endurance adaptations evident after the 11th week of training. This interference was evident by the lack of increase in $\dot{V}O2$ max and oxidative enzymes in the concurrent-training group. To test the belief that intensive simultaneous training for both strength and endurance is counterproductive, these researchers tested three groups, four days/week for 20 weeks. The endurance group trained on a bicycle ergometer, the strength group trained on an isokinetic device, and the combination group trained using both modes. The strength and combination groups had equal torque gains throughout the study. After 11 weeks, both the endurance and combination groups had similar gains in maximal oxygen comsumption. During the last half of the study, however, the endurance group had a significant additional gain in $\dot{V}O_2$ max, whereas the combination group showed no further increases. They concluded that simultaneous training may inhibit the normal adaptation to either training program when performed alone. They speculated that the compromise seen most likely depends on the nature and intensity of the endurance training stimulus. The protocol used by Nelson et al. (1990) involved isokinetic training forms for strength gains and endurance training of moderate intensity and long duration. In this case, subjects never trained for strength and endurance on the same day. This differs from the studies of Hickson (1980) and Dudley and Djamin (1985), who coupled strength training with an endurance program consisting of high-intensity cycle ergometry intervals. Because there is some question in these studies as to what protocols constitute true strength and endurance training, caution must be used in interpretating the results. The inconsistencies in methodology are evident throughout the literature; therefore, it is important to realize that different physiological adaptations may be due to slight variations in exercise training regimens.

Sale et al. (1990) assessed the effects of concurrent training on strength and endurance development by training one group for strength and endurance on separate, alternating days and another group using a same day strength/endurance training program. One group in this investigation did strength and endurance training in single sessions 2 days/week for 20 weeks. A second group performed strength training on 2 days/week and endurance training on 2 other days of the week. Strength training consisted of eight sets of 15-20 RM on a leg press machine and endurance training was six to eight 3-minute bouts of cycle ergometry exercise at 90-100% $\dot{V}O2$ max. The 4-day training group increased their 1RM more than the 2-day concurrent training group, but the groups increased similarly in knee extensor and flexor strength, cross-sectional area, and vastus lateralis mean fiber area. Increases in maximal oxygen consumption, repetitions with 80% of 1RM, repetitions with pre-training 1RM, and phosphofructokinase and lactate dehydrogenase activity did not differ between groups. They found that same-session strength and endurance training leads to greater increases in citrate synthase (CS) activity. No increases in max $\dot{V}O2$ or weightlifting performance in a long-duration endurance test were shown, however. These investigators concluded that strength development may be impeded by concurrent strength and endurance training without compromising hypertrophy. Furthermore, same-session training may enhance increases in CS activity but not in $\dot{V}O2$ max or weight lifting endurance. It should be noted that the endurance training in this study consisted of five 3-minute bouts on a cycle ergometer at a power output of 90 -100% $\dot{V}O2$max. This would not be considered true steady-state aerobic conditioning.

In a study by Hickson, Rosendoetter, and Brown (1980), previously endurance-trained individuals continued their aerobic conditioning and added strength training. Nine men participated in an exercise program designed to strengthen the quadricep muscles. They trained 5 days/week for a period of 10 weeks. On three days/week the subjects performed parallel squats (5 sets x 5 repetitions) and knee flexions (3 x 5). On alternate days they performed leg presses (3 x 5) and calf raises (3 x 20). The loads used were maximum for the given number of sets and reps, usually approximating 80% of 1RM. As strength increased, additional weight was added to maintain the resistance for the required repetitions. Following training, the subjects' endurance time to exhaustion increased while cycling (47%) and while running (12%) when they exercised at 100% of their pretraining $\dot{V}O2max$. No significant differences were seen in $\dot{V}O2max$ when expressed relative to body weight. The subjects' increases in short-duration (4-6 min.) endurance increased without increasing aerobic power or oxidative enzyme activity. These findings provide evidence that high resistance training is capable of significantly increasing high-intensity endurance when the muscles involved in training are used almost exclusively during the test.

Further evidence that changes in high-intensity endurance could be attributed to increased leg strength was provided by Marcinik, Potts, and Schlabach (1991). In this study, investigating the effects of strength training on lactate threshold and endurance performance, ten 25 - 34 year old males were assigned to a strength training group which exercised 3 times/week for 12 weeks while eight controls did no training. Strength training was composed of a whole-body circuit completed three times each workout. The exercises included bench press, hip flexor, knee extension, knee flexion, push-up, lat-pull, arm curl, parallel squat, and bent-knee sit-up. This circuit protocol involved lower resistance than conventional weightlifting and shorter rest intervals. Isokinetic peak torque values for leg extension and flexion and 1-RM values for leg extension were significantly improved after the 12-week strength training program. A 33% increase in cycling time to exhaustion was observed following training, while no differences were seen with the controls. Furthermore, there were significant reductions in plasma lactate levels at all relative exercise intensities, ranging from 55% to 75% of peak $\dot{V}O2$. Again, these findings indicated that improvements in endurance performance, independent of changes in $\dot{V}O2max$, appear to be related to increases in leg strength.

Bell et al. (1988) have shown that the sequential organization of strength and endurance training can influence the physiological adaptation to training. They studied sequential programs consisting of 5 weeks of aerobic development and 5 weeks of high-velocity resistance exercises. High-speed circuit training during the second 5 weeks maintained $\dot{V}O2$ max but not endurance gained at submaximal levels during the prior aerobic conditioning phase. Aerobic development was enhanced only with endurance training, regardless of training sequence. A few years later, Bell, Peterson, Wessel, Bagnall, and Quinney (1991) conducted a similar study. In this case, one group of subjects used low velocity resistance training consisting of heavy weight loads for 5 weeks prior to 5 weeks of endurance training while another group did the opposite training. Endurance exercise began at 40 minutes per session and increased by 5 minutes each week until 60 minutes of continuous rowing ergometer work was achieved. Workouts were performed on Monday through Friday at 75% peak $\dot{V}O2$. Circuit resistance training consisted of low velocity, high resistance concentric hydraulic training four times/week. Twelve stations were arranged, alternating between an upper- and lower-body exercises that specifically involved the muscles used for rowing. It was found that the improvements in peak $\dot{V}O2$ and submaximal exercise responses occuring after aerobic conditioning were not maintained with subsequent low speed, high intensity resistance training. Their findings suggested that completing resistance training before an endurance training phase, or vice versa, may be an alternative to training for both concurrently. If training for both in a sequenced fashion, it is further suggested that low-velocity strength training prior to endurance training may be more beneficial.

Hickson, Dvorak, Gorostiaga, Kurowski, and Foster (1988) investigated the possibility that development of strength is compatible with increasing aerobic capacity in individuals already trained in endurance events. The results did not describe any antagonistic effects of adding heavy-resistance training to constant endurance training regimens. Ten weeks of heavy squats and knee extension and flexion exercises were carried out by trained cyclists and runners. Leg strength increased an average of 30% while girth, citrate synthase activities, and maximal oxygen uptake went unchanged. It was suggested that a neural factor of more efficient motor unit recruitment patterns may be the reason for such adaptations. Short-duration endurance (4-8 min) was increased by 11% and 13% during cycling and running, respectively. Long-duration cycling to exhaustion at 80% $\dot{V}O2$ max increased from 71 to 85 min after the addition of strength training. It can be concluded from this study that endurance performances can be improved by weight training supplementation.

Research Inconsistencies

Several factors may contribute to whether the interaction between simultaneous strength training and aerobic conditioning will have an additive or antagonistic outcome on physiological training adaptations. Training program differences in the studies cited include the initial state of training, the modes of training (intensity, volume, and frequency of workouts), and the integration of the two forms of training (Sale et al., 1990). To further the controversy regarding exact physiological adaptations to concurrent resistance and endurance training, there are differences in experimental design and the lack of a consistent time course for the assessment of the variables.

Acute Responses to Strength and Endurance Training

Although the body of literature regarding long-term adaptations to concurrent strength and endurance training is small, there is enough information to understand such physiological changes. Research on the acute physiological changes to cross-training, however, is non-existent. Factors which may influence the acute effects of strength training on endurance conditioning include psychological effects, overwork, ammonia levels, and glycogen depletion.

Psychological Effects

One of the few studies involving same day strength and endurance training was carried out by Sale et al. (1990). These investigators found impaired strength development at the midpoint of a 20-week exercise program. A possible reason is that the strength training quality was diminished because subjects anticipated the 35-45 minute endurance activity that was to follow. It was hypothesized that fatigue or anticipation may have reduced the effort applied during the weightlifting.

Overwork Phenomenon

A maximal bout of strength training followed by steady state aerobic conditioning could push a person into a state of overwork caused by the short-term imbalance between exercise and recovery. Mellerowicz and Barron (1971) demonstrated that at given submaximal workloads, physiological parameters such as heart rate, ventilation, oxygen uptake, and blood lactate can be higher in an overtrained individual compared to someone in a well-rested state. The symptoms manifested from short-term overtraining, or overreaching as it is sometimes described, may be different from one person to another. Exercise exceeding the muscular stress tolerance of an individual may lead to muscular overstrain, resulting in transient local fatigue and muscular soreness (Kuipers & Keizer, 1988). According to Armstrong (1984), "muscular overstrain generally occurs after a single bout or repeated bouts of excessive exercise which results in structural damage to muscle fibers".

An individual not allowing for complete recovery of physiological homeostasis runs the risk of decreased work output capabilities. According to Kuipers and Keizer (1988), "With incomplete recovery it is assumed that the motor units, normally recruited and involved in a particular type and intensity of exercise, will be prematurely fatigued." Additional motor unit recruitment caused by increased nervous stimulation can help accomplish a demand for a higher energy output at a given work intensity. Kuipers, Verstappen, Keizer, Geurten, and van Kranenburg (1985) previously described these situations as requiring a higher oxygen cost, resulting in an increased heart rate, ventilation, and blood lactate at a given exercise rate. A particular workload may be perceived by a person as being heavier or harder compared to when they are in a normal well-rested state. This may be explained by the different pattern of recruitment at a certain exercise intensity.

Kuipers et al. (1985), studied ten subjects pedalling at 70% of a reference maximal workload for 5 minutes. The workload was then increased by 5% every 2.5 minutes, until they were exhausted. The maximal workload attained was considered as the test performance. Heart rate, respiratory variables, $\dot{V}O2$, blood lactate concentration, and RPE were determined at each work load. It was reported that increased energy production to meet the power required for a particular workload may cause reduced coordination and or decreased metabolic efficiency, which may lead to an increased stimulation of motor units. This, in turn, may result in a higher oxygen uptake, stimulation of the cardiorespiratory system, and an increase in lactate production. The recruitment of extra motorneurons due to poorer gross mechanical efficiency might explain the increase in rating of perceived exertion at a given intensity. It remains to be seen if an intense bout of leg strength training will alter the metabolic efficiency and coordination of an individual, resulting in a higher heart rate, oxygen consumption, and RPE during subsequent endurance work at a given workload. If this is the case, training intensities during aerobic work may need to be lower following strength training in order to elicit physiological responses similar to those when same-session weightlifting is not performed.

Ammonia

Elevated concentrations of ammonia during exercise and recovery have also been associated with overwork as described by Stone, Kearney, Fleck, Wilson, and Triplett (1991). Bannister et al. (1985) reported that, "increased levels of ammonia interfere with tissue oxidative metabolism and promote anaerobisis." They further explained that the resulting drop in tissue pH may lead to feelings associated with fatigue. Therefore, if same-session strength training and aerobic conditioning somehow elicit an overtraining effect, the result may be an inability to perform the workout fully because of fatigue brought about by increased blood ammonia levels.

Glycogen Depletion

Fatigue may occur as a consequence of muscle glycogen depletion. If muscle glycogen levels are already depleated or near depletion when endurance exercise begins, the body's capacity to carry out such activity would decrease. Furthermore, if the rate of anaerobic conversion of glycogen to lactate is greater than the capacity to transport lactic acid from muscle, H+ protons will accumulate to cause fatigue. Even if these protons can be removed from muscle, the high rate of anaerobic metabolism could quickly result in fatigue because of muscle glycogen depletion. Conlee (1987) discussed the Anaplerotic Theory, which describes why glycogen is needed for energy production. According to Conlee, ATP is being used up faster than it can be manufactured in a glycogen-depleted muscle. Thus, force output is diminished. Ahlborg, Felig, Hagenfeldt, Hendler, and Wahrenand (1974) concluded that "the capacity for prolonged strenuous work may be limited by the initial muscle glycogen content". When earlier-recruited motor units begin to fail, more fast twitch glycolytic motor units are called upon to sustain a given workload. As exercise duration increases and slow twitch fiber glycogen levels become increasingly lower, glycogen depletion of fast twitch muscle fibers occurs (Conlee, 1987). This would seem to be the condition when an individual is completing an exercise session involving a strength workout immediately followed by endurance training. Conlee (1987) also stated, "The fact that, at exhaustion during moderate to heavy workloads, many muscle fibers are completely devoid of glycogen supports the view that muscle fatigue could be caused by a deficiency in this energy substrate".

An acute bout of intense endurance exercise was found by Gollnick, Armstrong, Sembrowich, Shepherd, and Saltin (1973) to markedly reduce glycogen content and alter the mechanical properties of working muscle. Six subjects pedalled on a cycle ergometer at 150% of their aerobic power. Six 1-minute sprints were performed with 10 minute rest periods between each exercise bout. Biopsy samples were taken and analyzed for muscle recruitment patterns and glycogen content. Total muscle glycogen declined with the number of work bouts. Although the ATP-CP pathway may be the major source of energy during weightlifting, these repetitive sets of high-intensity exercise showed a greater contribution from glycogenolysis than was previously thought.

With regard to strength training, Tesch, Colliander, and Kaiser (1986) explained that reductions in the glycogen content of skeletal muscle are also evident after prolonged high resistance training. Nine strength trained athletes performed 5 sets each of front squats, back squats, leg presses, and knee extensions using barbells or variable resistance equipment. Each set was executed until muscular failure, usually occuring within 6 - 12 repetitions. Total performance time was 30 minutes with a 1:2 (exercise: rest) ratio. They showed a 26% decrease in muscle glycogen content after heavy weight resistive exercise. Additional support of muscle glycogen utilization during weightlifting was provided by MacDougall, Ray, McCartney, Sale, Lee, and Garner (1988), who reported a 25% decrease in muscle glycogen following three sets of maximal bicep single-arm curls. Finally, an investigation by Pascoe, Costill, Fink, Robergs, and Zachwieja (1993) found a 30% reduction in muscle glycogen of the vastus lateralis after high-intensity knee extensions.

The results from these studies indicate that glycogenolysis is a major energy delivery process for maximal sets of weightlifting exercise. Furthermore, these studies do not indicate that heavy resistance training can lead to glycogen depletion although marked reductions in muscle glycogen levels are clearly evident. Weightlifting coupled with immediate endurance training may, however, induce a state of glycogen depletion. It is this additive effect which could possibly lead to fatigue and perhaps increased fat utilization during same-session strength and endurance training. High muscle lactates after sets to failure suggest that muscle acidosis may also be a major cause of fatigue during such exercise.

Summary

It can be hypothesized that an increased muscular tension to maintain a particular intensity of aerobic work, performed immediately after heavy weightlifting, would alter metabolic parameters associated with fatigue and substrate shifts. Of particular interest would be changes in HR, $\dot{V}e$, $\dot{V}O2$, RPE, and RER variables due to the factors of overwork, which include glycogen depletion, increased ammonia levels, and psychological effects.

CHAPTER III

METHODS

The purpose of this study was to determine the immediate effects of lower extremity weightlifting on various submaximal aerobic parameters in college-age fitness enthusiasts. The following is a description of the methods that were used to gather and interpret the data from this experimental study. Specific and detailed descriptions of subjects, protocol, equipment and procedures, experimental design, and statistical analysis are presented.

Subjects

Twelve moderately active male and female recreational exercisers between the ages of 18 and 40 were solicited from Oregon State University to serve as subjects. Individuals selected had been participating in strength and aerobic training on a regular basis (3 times/week) for at least 3 months immediately prior to selection. Prospective subjects completed a physical activity log in order to determine frequency, duration, and intensity of current exercise program (Appendix C).

An informed consent form (Appendix A) was read and signed by all subjects before their participation in the study. The study complied with the conventions for the ethical treatment of subjects as described in *Medicine and Science in Sport and Exercise* (1993) and was approved by the OSU Institutional Review Board for the use of Human Subjects.

Protocol

The subjects reported to the OSU Human Performance Laboratory on four separate occasions. During the first visit, each subject reviewed and signed the informed consent document (Appendix A), medical questionnaire (Appendix B), and filled out an exercise training program evaluation (Appendix C). The experimental procedures were thoroughly explained by the investigator. Subjects subsequently completed a graded maximal cycle ergometer test in order to determine individual maximal oxygen consumption ($\dot{V}O2$ max). A plot of $\dot{V}O2$ against power output for each subject was used to calculate the appropriate workload corresponding to 65% of $\dot{V}O2$ max. During the second session, subjects performed various isotonic leg exercises to determine an 8 repetition maximum (the amount that can be lifted eight times but not nine) for each. Exercises included leg presses, leg extensions, and leg curls on Universal gym equipment. On the next visit, a submaximal experimental trial was completed on a cylce ergometer at 65% $\dot{V}O2$ max. On the fourth visit, a second submaximal experimental trial was performed alone or after a bout of leg presses, leg extensions, and leg curls on Universal gym equipment. During both submaximal tests metabolic measurements of HR, $\dot{V}e$, $\dot{V}O2$, RER, and RPE were taken. The results from both submaximal experimental trials of each group were then compared to each other. These procedures are outlined in greater detail below.

Maximal Exercise Test

To evaluate each subject's aerobic capacity, a maximal incremental cycle ergometer exercise test was performed at the beginning of each subject's participation in the study to determine $\dot{V}O2$ max. From this, determination of the correct workload for the submaximal experimental trials was made. All participants were fully briefed on the procedures involved prior to initiation of the maximal test. Subjects pedalled at a self-selected pace on a Sensormedic cycle ergometer (ergo-metrics 800-S #02921022S). Following a 5-minute warm-up at 50 watts, the power output was increased by 25 watts every minute until voluntary termination due to fatigue. The maximal oxygen consumption test took approximately 10-15 minutes. The criteria for achievement of $\dot{V}O2$ max was the attainment of any two of the following:

1) an increase in workload without any concurrent increase in $\dot{V}O2$
2) a respiratory exchange ratio above 1.15, or
3) a heart rate approximating the age-predicted maximum (220-age).

During the test of aerobic capacity, a standard open circuit spirometry method was employed. While wearing a noseclip, the subjects breathed through a mouthpiece into a 2700 Hans-Rudolf non-rebreathing two-way valve connected by a hose to a Sensormedics 2900 metabolic cart for the determination of oxygen consumption ($\dot{V}O2$), ventilation ($\dot{V}e$), and respiratory exchange ratio (RER). This permitted quantification of expiratory volumes and concentrations of oxygen and carbon dioxide, from which volumes of oxygen consumed were determined. The expired air was collected and analyzed in 20-second intervals. The metabolic cart was calibrated using gas samples of known oxygen and carbon dioxide concentrations prior to each test. The flow meter was also calibrated with a 3 liter calibration syringe at the beginning of each testing day. The subjects' rating of perceived exertion (RPE) was taken every 2 minutes. A Sensormedics MAX-1 electrocardiograph was also used to continuously monitor heart rate. A V5 electrode configuration was used for this setup. Trained laboratory personnel, certified in CPR administered the exercise tests.

Determination of Weightlifting Workloads

Subjects were taken to the strength training room for determination of their 8 repetition maximums (the amount of weight that can be lifted eight times but not nine). A Better Builds leg press, Universal leg extension (model EN811497621), and Universal leg curl (model EN811497622) resistance equipment were used, as these pieces of muscular resistance equipment are typical to this type of lower body training. Subjects were given a demonstration of the proper form and technique to be used when lifting. They then performed the leg press initially using a moderate weightload. The load was increased until the 8RM was reached. This procedure was then followed for the leg extension and leg curl activities. A rest period of 2 to 3 minutes was allowed before determination of the 8RM for a new exercise was begun in order to simulate the strength training session.

Submaximal Experimental Trials

Subjects reported to the laboratory having refrained from strenuous physical activity for the previous 48 hours. They were fitted with a V5 electrode configuration and connected to the ECG monitor upon entry into the lab. After attaching the noseclip and inserting the mouthpiece, subjects warmed up for 5 minutes at 50% $\dot{V}O2$ max. The subjects then cycled at 65% $\dot{V}O2$ max for 30 minutes as expired air was continuously monitored. Heart rate, $\dot{V}O2$, $\dot{V}e$, and RER were collected throughout the testing period. A cool-down period of 5 minutes followed the exercise session.

For the second experimental trial, half of the subjects performed a second submaximal cycle ergometry test using the same protocol as the first. This was be the control group. The other half of the subjects reported to the strength training facility and perform a series of leg stretching exercises. They then completed the leg workout beginning with the leg press, moving to leg extensions, and finished with leg curls. Each exercise consisted of three sets of eight repetitions, or until muscular failure, at the subjects' previously identified 8RM. Subjects were monitored for correct form and lifting techniques and provided encouragement throughout the session. A maximum of 3 minutes rest was given between sets. Following the completion of the weightlifting exercises, subjects were immediately escorted to the Human Performance Laboratory for the ensuing submaximal cycle ergometry test which followed the protocol guidelines described above.

Food Intake

Subjects were asked to maintain their regular eating habits throughout the testing period. They were asked to eat meals similar in content and consume the same amounts the day before and the day of each testing period.

Experimental Design

A randomized control group pre-test post-test experimental design was used for this study. For the treatment, the dependent variables were HR, $\dot{V}O2$, $\dot{V}e$, RER and RPE. The exercise testing sessions were at least five days apart to allow for complete recovery of subjects between each test.

Statistical Analysis

An unpaired t-Test was used to analyze the data. A one-way ANOVA was also used to test subject randomization. It was determined that six subjects in the experimental and control groups were needed to achieve a power of .80 of detecting a large effect size between groups with alpha set at 0.10.

CHAPTER IV

RESULTS

The effectiveness of experimental and control group randomization was tested using the subject characteristics of age, height, weight, and exercise frequency. Mean values are given in Tables 1 and 2. Baseline measurements of heart rate, oxygen consumption, ventilation rate, respiratory exchange ratio, and rating of perceived exertion were obtained after the first submaximal exercise trial for each subject. The group means for these parameters are shown in Table 3. No significant differences ($P > .05$) were evident using a one-factor analysis of variance for both the subject characteristics and baseline measurements. This statistical procedure indicates that randomization of subjects into experimental and control groups was achieved.

Table 1. Subject Characteristics - Control Group

Subject	Age (yr)	Height (in)	Weight (lb)	AE [1] (times/wk)	WL [2] (times/wk)	$\dot{V}O2max$ ($ml/kg^{-1} \cdot min^{-1}$)
01	22	68	176	5	3	50.61
05*	24	68	133	5	3	38.76
07	20	70	162	3	2	52.20
09	19	70	162	5	3	63.02
10*	22	69	152	5	5	35.30
12	29	74	186	6	2	66.46
mean	22.6	70	162	4.8	3	51.06

* female

[1] AE = aerobic exercise frequency

[2] WL= weightlifting frequency

Table 2. Subject Characteristics - Experimental Group

Subject	Age (yr)	Height (in)	Weight (lb)	AE (times/wk)	WL	$\dot{V}O2max$ (ml/kg^{-1}min^{-1})	combined 8-RM (lb)
02	23	70	167	3	5	50.65	300
03*	22	67	189	4	5	38.90	240
04	28	71	165	6	2	58.00	300
06*	21	61	115	3	3	43.50	145
08	21	72	180	6	3	63.58	360
11	26	73	173	3	2	58.00	280
mean	23.5	69	165	4.3	3.3	52.11	270

Table 3. Average Baseline Measurements (trial #1)

Group	HR(bpm)	$\dot{V}O2$(ml/kg/min)	$\dot{V}e$(L/min)	RER	RPE
Control	157.8	34.9	65.9	.972	13.4
Experimental	152.2	34.8	65.4	.971	14.0

An unpaired t-Test was employed to evaluate the influence of strength training on the various physiological parameters during submaximal aerobic exercise. As shown in Table 4, only heart rate changed significantly due to the intervention, whereas $\dot{V}O2$, $\dot{V}e$, RER, and RPE were unaffected by the strength training session. The mean difference between trial 1 and trail 2 for each parameter was calculated.

The mean difference between submaximal exercise trials for heart rate within the control group was -1.0 beats per minute. The experimental group, on the other hand, showed a statistically significant mean difference of 8.83 bpm between trials, due to the intervention.

The control group had a mean difference of 0.13 ml/kg min for $\dot{V}O2$ between trials and the experimental group illustrated a 1.61 ml/kg min difference between trials. Ventilation mean differences between trials were 2.54 L/min and 1.32 L/min for the control and experimental groups, respectively. The respiratory exchange ratio mean differences over trials was -.015 for controls and -.32 for the experimental group. Finally, a .38 mean difference in RPE was calculated for the controls compared to a .10 difference for the experimental group. With the exception of HR there were no statistically significant changes in any of the above variables between trials 1 and 2 for either group.

TABLE 4. Effects of Strength Training (group means)

	control		experimental		
Parameter	trial 1	trial 2	trial 1	trial 2	p-value
HR (bpm)	158	157	152	161	.0475 *
$\dot{V}O2$ (ml/kg min)	34.88	35.01	34.76	36.37	.2502
$\dot{V}e$ (L/min)	66.0	68.5	65.4	66.7	.5689
RER	.972	.957	.971	.948	.5773
RPE	13.4	13.7	14.0	14.1	.4940

* statistical significance

This investigation attempted to uncover the acute effects, if any, of lower body strength training on various physiological variables during a thirty minute submaximal cycle ergometry test. It was expected that mean values of heart rate during submaximal work would be higher after a strength training session compared to heart rate measured without prior strength training. This expectation was confirmed by the results of this study. Significant heart rate differences between submaximal exercise trials were evident in the experimental group compared to the controls. Furthermore, the investigator predicted that mean values of oxygen consumption, ventilation, and rating of perceived exertion would also be higher and that the respiratory ratio would be lower after strength training compared to mean submaximal exercise values without previous weightlifting. These predictions were not supported by the results of this study.

Increases in heart rate due to higher exercise workloads are often associated with concurrent increases in other cardiorespiratory and metabolic variables. Because of this, it is challenging to devise possible explanations of why heart rate increases were evident in an exercise situation without parallel increases in $\dot{V}O2$, $\dot{V}e$, RER and RPE. This discussion will attempt to bring forth plausible mechanisms to explain the results of this investigation.

Heart Rate (HR)

Of primary importance to this discussion is the question of why heart rate was elevated following the strength training session but oxygen consumption was not. When describing the separate phases of a cross-training exercise session such as this (weight lifting and cycle ergometry), it is important to view the phases independently to study the effects of one on the other. In this case, the weightlifting (WL) activity elicits physiological responses which may "spill over" to affect the aerobic conditioning part of the exercise. This situation illustrates the influences of an anaerobic activity on an aerobic activity.

The heart rate/oxygen consumption relation is often used to describe exercise intensity changes. It has been consistently reported that the HR at a given $\dot{V}O2$ is higher during WL than during dynamic low-resistance exercise such as treadmill running or leg cycling (Hempel and Willis, 1985; Hurley, Seals, Ehsane, et al., 1984). The mechanism underlying higher HR during WL compared with dynamic low-resistance exercise at the same $\dot{V}O2$ is undetermined. However, Collins et al. (1991) described factors which in combination may contribute to a higher HR/$\dot{V}O2$ during weightlifting. It is postulated that HR may increase during WL due to elevated sympathetic activity, reflected by the rise in plasma catecholamine concentration (Hurley et al., 1984). Elevated sympathetic activity during strength training may be caused by the sustained static exercise (gripping of the bar) evident during such exercise. Second, an increased HR may also be caused by performance of the Valsalva maneuver, which has been shown to cause tachycardia and to significantly increase muscle sympathetic nerve activity through decreased arterial and low blood pressure baroreceptor stimuli (Collins, Cureton, Hill, and Ray, 1991). Third, increased sympathetic activity could be caused by stimulation of chemosensitive Type IV afferent fibers due to decreased muscle cell pH (Mark, Victor, Nerhed, and Wallin, 1985). Weightlifting elicits a greater blood lactate concentration, which many researchers believe reflects higher muscle lactate and lower muscle pH, at a given submaximal $\dot{V}O2$.

Heart rate may also be elevated to a greater extent during strength training compared to aerobic exercise because of greater fast-twitch muscle fiber recruitment (Collins et al., 1991). This increased recruitment is assumed to be due to a substantially greater force which is required during WL. Activation of fast-twitch fibers during strength training elicits a greater exercise pressor reflex than activation of slow-twitch fibers.

To achieve a higher cardiac output to sustain muscular exercise, HR, stroke volume, or both must be increased. The increased heart rate response evident during WL results as a compensatory mechanism due to a reduction in stroke volume. It appears that stroke volume decreases during strength training exercise because of an elevation in intramuscular pressure in combination with elevated intrathoracic and intra-abdominal pressures (Bezucha, Lenser, Hanson and Nagel, 1982). As the percent of maximal voluntary contraction increases, more muscle fibers are recruited for the effort, and intramuscular tension and pressure increase. If intramuscular pressure exceeds intravascular pressure, blood flow through exercising muscle would be restricted or halted (Collins et al., 1991). Although leg extension exercise is mostly a dynamic type of exercise, it has a substantial static component. Central and peripheral adaptations suggest that large intramuscular forces are developed which significantly increase peripheral resistance and impede venous return (Miles, Owen, Golden, and Gotshall, 1987). A reduction in venous return (decreased preload) along with elevated arterial pressures (increased afterload) would reduce stroke volume. Therefore, to maintain adequate blood flow to support the $\dot{V}O_2$, an elevation in HR must occur.

Another cause of decreased stroke volume during strength training exercise is diminished plasma volume. Knowlton et al. (1987) studied the plasma volume response following squat lift exercise, which uses a large lower body muscle mass. Plasma volume was decreased 17.9% after subjects completed eight sets of eight repetitions at 55% of their 1-RM. In a similar study, Collins et al. (1989) demonstrated that plasma volume decreased linearly in relation to the intensity of WL. Subjects with previous WL experience performed a WL session consisting of three circuits of four exercises: bench press, bent-over row, arm curl, and parallel squat. This standardized bout of WL was performed at four different intensities (40%, 50%, 60%, and 70% of 1-RM) on separate days. Ten repetitions were completed over a 30-second period followed by 30 seconds of rest. Again, plasma volume decreased linearly in relation to the intensity of weightlifting.

Several factors contribute to the decreases in plasma volume seen in the above studies. One factor that affects the amount of plasma volume change is capillary fluid pressure. An increase in arterial pressure will promote the filtration of plasma into interstitial spaces. Plasma volume shifts are also influenced by osmotic gradients. The breakdown of glycogen, production of lactate, and accumulation of other metabolites in the active muscle during exercise serve to increase intracellular osmolarity. This may result in shifts of fluid from the interstitial to intracellular and from vascular to interstitial spaces (Collins, Cureton, Hill, and Ray, 1989). A large transient intramuscular-vascular lactate gradient, which exists during weight training, further exacerbates plasma fluid losses. Miles et al. (1987) examined the changes in central and peripheral hemodynamics and myocardial contractility elicited during the performance of maximal leg extension exercise and found that stroke volume fell even though indices of myocardial performance indicated an enhancement of contractility.

According to Collins et al. (1989) plasma volume is restored to the resting level in approximately 30 minutes regardless of the exercise intensity or magnitude of the plasma volume change. The time course of plasma volume recovery was very similar to that of blood lactate. "Restoration of vascular volume would result from a decline in intravascular hydrostatic pressure, clearance of lactate and other metabolites from muscle and the interstitium, and return of fluid to the circulation via the lymphatics" (Collins et al., 1989). This is an important point with regard to the current study of WL effects on subsequent cycle ergometry. The cycling exercise, initiated within five minutes of a strength training session, was performed for 30 minutes. According to the above stated theory on recovery, this is not sufficient time for plasma volume to equilibrate to normal levels. Thus, the increased HR during the second phase of the cross-training exercise may be due to a decrease in plasma volume, which would decrease stroke volume and necessitate a higher heart rate to achieve the appropriate cardiac output.

Oxygen Consumption ($\dot{V}O2$)

It is well known that oxygen uptake continues to increase after the initial three minutes of exercise at work rates requiring more than 60% $\dot{V}$O2max. This slow rise in $\dot{V}$O2 has previously been attributed to the removal of blood lactate. Other probable causes include increased muscle and core temperatures, increased ventilation, and changes in substrate utilization. Apparently, there was no oxygen drift during the 30 minute cycle ergometer submaximal test at 65% $\dot{V}$O2max due to WL in this investigation. This suggests that the WL did not increase the relative intensity of the subsequent aerobic activity.

Although the muscles of the legs were called upon to perform work which subjectively "fatigued" the subjects during WL, apparently there were no carry-over effects which altered $\dot{V}$O2. This finding does not coincide with research done on $\dot{V}$O2 drift during constant-load work (Hagberg, Mullin, and Nagel, 1978). In this study 18 subjects exercised for 20 minutes at 65% and 80% of $\dot{V}$O2max on a cycle ergometer. $\dot{V}$O2, $\dot{V}$e, RER, blood lactate, and rectal temperature were monitored. This investigation indicated that an upward drift in $\dot{V}$O2 occurs during dynamic steady-state forms of exercise at 65% and 80% of $\dot{V}$O2max.

Westerlind, Byrnes, and Masseo (1992) stated that, with muscle damage, certain fibers are no longer able to generate sufficient force and that additional motor units are recruited to maintain a given work output. However, the damaged fibers continue to use oxygen, along with the newly recruited fibers. This phenomenon results in a slow increase in $\dot{V}O2$ during eccentric exercise (Dick and Cavanaugh, 1987). This would apply in cases where individuals are experiencing delayed onset muscle soreness from their weight training program, but no subjects reported any incidents of muscle soreness during the study.

The Q_{10} relationship, which links increases in temperature with increases in mitochondrial respiration and the subsequent increases in $\dot{V}O2$, is not normally a factor during weightlifting. It is not known from the procedures of this investigation whether the WL elicited an increase in core body temperature. Alterations in the levels of hormones such as thyroxine, epinephrine, and/or norepinephrine may also contribute to the increase in $\dot{V}O2$. Based on the above information, it must be concluded that $\dot{V}O2$ increases due to the drift mechanism common to prolonged running events were not seen in this investigation. This may be the case as the present study used a different mode of endurance exercise (cycle ergometer vs. running) or because of the relatively short amount of exercise time.

Astrand (1986) discussed the role of efficiency during cycling exercise. Unlike other endurance activities, the mechanical and muscular efficiency of cycling is not greatly affected by environmental factors such as heat or hypoxia nor by fatigue due to previous exercise. It has been shown that no performance changes are seen during cycling under these various conditions, as the efficiency and the overall workload remain similar.

Since no increased demand for oxygen was seen during the submaximal ergometry following WL, it can be concluded that the ventilatory, myocardial and thermoregulatory factors which normally contribute to increases in $\dot{V}O2$ were not significantly taxed during the intervention. Ventilation was measured and, in fact, no changes were seen.

Respiratory Exchange Ratio (RER)

It was postulated that weightlifting would begin depleting muscle glycogen stores to a point where increased fat utilization would be evident during the cycle ergometry. This, in turn, would be indicated by a lower respiratory exchange ratio in the trial that followed WL. In fact, the RER values remained constant between trials, indicating that strength training, as performed in this experiment, did not lead to sufficient depletion of glycogen stores to alter metabolic substrate utilization.

Even though much higher metabolic activities of the glycolytic enzymes have been found in the muscle tissue of weight lifters, the energy requirements during strength exercises appear to be met exclusively through the depletion of energy-rich phosphates (Keul, Haralambie, Bruder, and Gottstein, 1978). Although carbohydrates are thought to be the primary energy source during weightlifting, it appears that the storage levels were sufficient after the session of lower body strength training. Weightlifting of this sort does not lead to the use of fat as an energy source. To confirm this, Keul et al. (1978) found no changes in the biochemical parameters of triglycerides, FFA, glycerol, beta-lipoproteins, or total lipids during one hour of total-body weightlifting.

Since walking has been shown to increase FFA metabolism, Hetzler and colleagues (1986) studied the influence of walking on substrate utilization during subsequent running exercise. In this study endurance-trained subjects ran on a treadmill for 40 minutes at 65% of their $\dot{V}O2max$. Half preceded the run by resting (without warm-up) and the others walked for 20 minutes before their run. Significantly different trends in FFA concentrations were found between trials. The percentage of energy derived from fat metabolism was significantly higher in the walking warm-up group. It was further calculated that an average of 23.1 grams of carbohydrate was spared during exercise due to the performance of a warm-up activity. They concluded that preliminary exercise can cause a shift in substrate utilization such that proportionately less carbohydrate and more fat would be metabolized during the early portion of an endurance event.

With the results of the Hetzler (1986) study in mind, one might suggest that WL may also be used as a warm-up activity which would similarly initiate an increase in FFA mobilization. Thus, we would see an increased utilization of fat (decreased RER) during an endurance activity such as stationary cycling. The findings of the present study refute these predictions, however. Similar RER values during ergometry, with and without prior WL, may rule out the possibility of using weight lifting as an effective warm-up activity to enhance plasma FFA utilization as a substrate during submaximal exercise.

Although lactate levels were not measured, it is possible that the WL can cause a significant increase in lactate, which has been discussed by Astrand (1986), to inhibit FFA mobilization. Again, because RER values remained similar in the present study, this did not prove to be the case. From the results of the present investigation, weight lifting of the variety used with this population can not be considered in the category of FFA utilization-enhancing preliminary activities or a FFA inhibiting activity. It should be noted, though, that the previous WL, while not increasing fat utilization, did not cause a decrease in its use, either. Perhaps more intense and longer duration strength training and/or aerobic conditioning sessions would elicit greater changes in RER values.

It should also be noted that extremely strict diet and physical activity control was not possible in this investigation due to time and personnel constraints. Subjects were informed not to change any eating habits from their normal diet or partake in strenuous exercise two days prior to any testing sessions. It was made clear that no exercise was to be performed the day of any test and that normal meals should be eaten on those days. While these instructions were explicitly made, it remains possible that RER values may not be reflective of a subject's typical nutritional and physical status. Since no significant difference was shown between trials for either group, this issue becomes less confounding to the overall results.

Rating of Perceived Exertion (RPE)

This subjective measurement was used to capture any responses which may pertain to the psychological effects of weight lifting on subsequent endurance activity. The mental perceptions of physiological strain did not vary from one trial to the next due to the strength training session. Interestingly, many subjects commented on a feeling of fatigue in the legs immediately following the weight lifting but then reported similar ratings based on perceptions of exertion after the warm-up period and continuing throughout the 30-minute ergometry exercise period. It may be that the reported lactic acid "burn" and "muscle pump" were due to a temporary increase in peripheral blood flow, more specifically a shift to the lower extremities during the leg press, leg extension, and leg curl exercises. With the initiation of cycling and a continuous dynamic action of the legs, this blood pooling subsides and venous return increases would occur to facilitate a greater cardiac output.

The practical application of the current findings deal primarily with the control of exercise intensity. Many fitness enthusiasts and recreational athletes use heart rate as the main indication of an activity's intensity. A common method is to determine a target heart rate zone for exercise based on age, predicted maximum heart rate, and desired level of exercise. It becomes more complicated to monitor true physiological responses if, in fact, a strength training session alters heart rate for individuals performing a cross-training regimen like the one in this investigation. If heart rate is elevated during submaximal endurance activity after strength training without concomitant increases in VO2 compared to the same workload without previous WL, adjustments must be made to achieve the same exercise stimulus. For instance, if an individual partakes in a cycling activity without previous ST, a heart rate (e.g., 156 bpm) will be observed for a given workload (e.g., 200 watts) and oxygen consumption (e.g., 37 ml/kg/min). The same individual decides to cross-train a week later, performing a lower-body weightlifting session prior to the same cycling event. Based on these findings, a significantly higher HR (165) will be achieved for the same workload (200 watts) and metabolic demands (37 ml/kg/min). This is to say that when this individual is judging exercise intensity by HR alone, as many exercisers of this age and training ability do, it should be understood that HR is expected to be higher (approx. 9 bpm) without an increased training effect.

Again, this issue becomes important if individuals determine their exercise session by HR alone. If they are unaware of the immediate effects of WL on HR, they would most likely perform a lesser workload. Many individuals, however, perform their conditioning workout on a machine, exercising at a usual level of intensity controlled by the settings on the equipment. If this is the situation, they will notice a higher HR upshot after WL. Therefore, if a fitness enthusiast is establishing exercise intensity by HR alone, he/she will achieve a lesser training stimulus during the aerobic conditioning phase of cross-training. Those judging exercise intensity by a predetermined equipment setting will achieve a higher HR but probably not a greater training stimulus.

This information may be useful to fitness consultants and exercise trainers as well as exercise and strength physiologists who are in a situation of training athletes or fitness enthusiasts utilizing similar cross-training workouts. The acute effects of strength training may alter the manner in which someone judges subsequent aerobic conditioning.

While the available data indicates HR as being the only parameter that is significantly affected by the WL intervention, it should be noted that certain trends may be present which would support much more of the hypotheses than was interpreted from the statistical analysis. When refering to Appendix H it is evident that the experimental group $\dot{V}O2$ is rising while the control group $\dot{V}O2$ remains fairly stable over trials. This trend is lesser in Appendices I and J for $\dot{V}e$ and RER parameters but the graphs are clearly evident of an interaction effect. This interaction was not statistically significant using the current sample size of 12. However, a larger sample size, closer to 25, would increase power and, therefore, allow the interaction effects to become statistically significant.

CHAPTER V

SUMMARY, CONCLUSIONS, RECOMMENDATIONS FOR FUTURE RESEARCH

The purpose of this investigation was to determine the acute effects of strength training on various cardiovascular, ventilatory, and metabolic parameters during subsequent aerobic exercise. Six fitness enthusiasts, previously trained in weightlifting and cardiovascular conditioning, performed a weightlifting session consisting of three Universal equipment leg exercises (leg press, leg extension, leg curl). Immediately afterward, the subjects exercised on a cycle ergometer at 65% of their $\dot{V}O2max$ for 30 minutes. Physiological parameters of heart rate (HR), oxygen consumption ($\dot{V}O2$), ventilation ($\dot{V}e$), respiratory exchange ratio (RER), and rating of perceived exertion (RPE) were measured during submaximal trials and compared to controls who performed cycle ergometry without a previous strength training session.

It was hypothesized that 1) HR, $\dot{V}O2$, $\dot{V}e$, and RPE would be increased during aerobic conditioning exercise after weightlifting and 2) RER would decrease during aerobic exercise after weightlifting.

The results supported, in part, hypothesis #1, indicating that HR increased significantly (+9 bpm) due to the strength training intervention. The other aspects of hypothesis #1 and hypothesis #2 were refuted by the results, however, which showed that $\dot{V}O2$, $\dot{V}e$, RER, and RPE all remained similar between trials for both the control and experimental groups. Various mechanisms which may have caused an increase in HR without similar increases in ventilatory and metabolic indices have been discussed. These include, but are not limited to, an elevated HR "spill over" effect due to musculoneural and hemodynamic changes elicited by strength training. $\dot{V}O2$ drift, often associated with this type of submaximal exercise, was not seen in this study. Finally, changes in substrate utilization which might have occurred due to glycogen depletion and enhanced FFA mobilization, were not found with this particular type of exercise regimen.

This study could be repeated in the future with changes in the protocol emphasizing a greater weightlifting volume (more repetitions, more sets, or a greater number of exercises) and a longer submaximal exercise trial (longer than 30 min). More stringent control of diet may be achieved by having subjects fill out daily diet records that are checked before every test as well as accurate monitoring of daily physical activity. The subjects used in this study (college-aged fitness enthusiasts) were of a fairly specific age and training status. Practical application of these results can only be used for a population with similar characteristics. Further implications are unknown with a different population than the one used in this study. The same results may not be evident with subjects of different age or training background. Future research should focus on the same type of cross-training regimen involving lower body strength training and endurance activity performed by the elderly or with individuals who are untrained.

It also remains to be seen whether the same applications can be made for differently ordered cross-training or the use of varying modes of strength training and aerobic conditioning. More drastic or different results may be found when a protocol utilizing free weights or plyometrics is used for the strength training phase. Exercises such as parallel squats, free-standing lunges, and calf raises may elicit entirely different responses due to the varying nature of these commonly used lifts. Furthermore, it is unclear if strength training muscle groups other than the legs would affect subsequent aerobic exercise in the same manner. Will a maximal bout of upper body weightlifting increase heart rate or change oxygen demands during the second phase of a cross-training workout?

It may also become clear that similar results are not evident when applied to conditioning activities other than cycling. Future research should study the acute effects of strength training on other commonly performed endurance exercises such as running, rowing, and stair-stepping.

With the availability of more money, personnel, and equipment a greater number of parameters could be tested under the same circumstances. For instance, blood lactate levels could be quickly analyzed using finger prick samples and core body temperature measurements using tracer or rectal probe techniques would provide additional valuable insights into the body's response to this type of exercise training.

Finally, to further enhance our understanding of concurrent strength training and aerobic conditioning, studies must be pursued which describe the acute effects of endurance activity on subsequent weightlifting performance. Only then will fitness enthusiasts and recreational athletes be able to make a clear and scientific decision as to which order of activity is best for their individual cross-training needs.

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APPENDICES

Appendix A

CONSENT FORM

The Acute Effects of Strength Training on Various Metabolic Parameters During Subsequent Aerobic Exercise

Investigators: Anthony Wilcox, Ph.D., and Jason Wallis, C.S.C.S.
Department of Exercise and Sport Science, Oregon State University

Purpose: The purpose of this investigation is to study the effects of a strength training session on various metabolic parameters (heart rate, oxygen consumption) during an aerobic exercise session that immediately follows the weightlifting.

I have received an oral explanation of the study procedures and understand they entail:

1. **A test of maximal oxygen consumption ($\dot{V}O2$ max)**
   At the onset of my participation in the study, I will perform a test of my aerobic capacity. I will undergo a stationary cycle test beginning at an easy workload of 50 watts and slowly increasing in intensity. After a five minute warm-up, the workload will be increased by 30 watts every minute until I become too fatigued to continue or request to end the test. The test will take 10-15 minutes, with only the final few minutes being at a high intensity. During the test, I will breathe room air through a mouthpiece so that the amount of oxygen my body is using can be determined. Trained laboratory personnel, certified in CPR, will administer the test. My heart rate will be monitored electrocardiographically (ECG) and my rating of perceived exertion (RPE) will be recorded regularly.

2. **A test of leg strength**
   If I am randomly assigned to the experimental group, I will be performing an 8-repetition maximum (8RM) test in order to determine the amount of weight I can lift eight times but not nine. The exercises I will be performing will be leg presses, leg extensions, and leg curls on Universal resistance equipment. I will perform the leg press using a moderate weightload. The load will be increased until my 8RM is reached. I will then repeat this procedure for the leg extension

and leg curl exercises. A rest period of 2 to 3 minutes will be allowed between my sets.

3. **Tests to investigate the physiological responses during stationary cycling**
I will report to the laboratory having refrained from strenuous physical activity for the past 48 hours. I will then be fitted with a heart rate monitor and connected to an ECG machine. After being fitted with the breathing apparatus, I will warm up and then cycle at 65% of my $\dot{V}O2max$ (determined previously from the max test) as my expired air and heart rate are continuously monitored for 30 minutes. My rating of perceived exertion (RPE) will also be periodically assessed. A cool-down of five minutes will follow the exercise session. I will repeat this same test approximately one week later with or without prior weightlifting, depending on the group I am assigned to.

4. **A strength training workout for the legs**
If I am assigned to the experimental group, I will report to the strength training facility for the second experimental trial to perform a series of leg stretching exercises. I will then perform the leg workout beginning with leg presses, moving to leg extensions, and finishing with leg curls. Each of these exercises will consist of three sets of eight repetitions at my previously determined 8RM. I will be allowed a maximum of three minutes between sets. Following the completion of my strength training session, I will be immediately escorted to the Human Performance Laboratory for another aerobic cycle test which will follow the procedures described above.

Risks

I understand that the test of maximal aerobic capacity presents a very slight chance of precipitating a cardiac event (such as abnormal heart rhythms) or possibly death. However, the chance of such a situation is very remote (less than 1 in 10,000) since I am good health and have no known symptoms of heart disease. Furthermore, the test will be administered by experienced laboratory personnel, trained in CPR, monitoring for signs of exercise intolerance.

I am aware that the weightlifting presents a small chance of muscle strains or soreness. Since I am from a healthy population, will be advised about correct lifting, have experience with weightlifting, and am not performing any maximal lifts, I am not likely to experience any muscle injury.

Benefits
The benefits from my participation in this study include contributing to the understanding of the immediate effects of strength training on aerobic conditioning exercise. I will also gain information regarding my aerobic capacity and leg strength. This knowledge will be helpful in making decisions relating to my exercise habits and training program.

I understand that my participation in the study will entail four laboratory sessions, requiring a total time commitment of approximately five to six hours over a time period of two to three weeks.

I understand that confidentiality will be maintained by assignment of a code number upon my entry into the investigation. All data will be recorded using the code number. The list containing the names of the subjects will only be available to the researchers in this study. I will not be identified in any way in the presentation or publication of the results of the study.

Questions about the research or any aspects of my participation in it should be directed to Dr. Anthony Wilcox, Dept. of EXSS (737-5922) or Jason Wallis (757-0337). I understand that the University does not provide a research subject with compensation or medical treatment in the event the subject is injured as a result of participation in the research project.

I have been completely informed and understand the nature and purpose of the research project. The researchers have offered to answer any further questions that I may have. I understand that my participation in this study is completely voluntary and that I may withdraw from the study at any time without prejudice or loss of benefits to which my participation entitles me.

I have read the foregoing and agree to participate in this study.

--- -------------------

Subject's Signature Date

Subject's Address

--- -------------------

Investigator's Signature Date

Appendix B

MEDICAL QUESTIONNAIRE

Name ______________________________ Date ______

Address __________________________ Phone__________

Age ____ Gender ___ Height _____ Weight ________

Circle the appropriate responses:

1. Have you smoked cigarettes regularly in the last 5 years?

   yes no

2. Have you been diagnosed as having high blood pressure?

   yes no

3. Have you ever been treated for "sugar diabetes" (diabetes mellitus)?

   never with pills with insulin injections

4. Did either of your parents or any of your siblings have a "heart attack" or bypass surgery prior to the age of 55 years?

   yes no

5. Have you ever had an elevated blood cholesterol level (over 240 mg/dl)?

   do not know no yes

   Do you know your blood cholesterol level? ________ mg/dl

6. Describe your exercise habits.

7. List any prescription medications you are taking and give amounts.

Appendix C

Exercise Training Program Evaluation

Name ______________________________ Date ____________

Address ____________________________ Phone __________

Age_____ Gender ____ Height _______ Weight ___________

Describe your weekly aerobic conditioning workouts. Be as detailed as possible with regard to type, duration, frequency, and intensity of training.

Activity	Frequency	Duration	Intensity

Describe your weekly weightlifting routine. List the lift or exercise, frequency, number of sets, repetitions, and weightload.

Exercise	Frequency	Sets	Reps	Weight

Appendix D

WALLIS STUDY DATA FORM

Subject ____________________ Height ________ in

Age ______ Weight ________ lbs

Date of max test __________

Date of submax-1 __________

Date of submax-2 _________

Seat Height ________

$\dot{V}O2max$ _________ ml/kg/min = _______ watts

65% $\dot{V}O2max$ ________ ml/kg/min = ______watts

Submax-1 Test

HR ____ bpm RPE _______

$\dot{V}O2$ ______ ml/kg/min RER _______

$\dot{V}e$ ______ L/min

Strength Training

8RM workloads Leg Press __________ lbs

Leg Extensions _________ lbs

Leg Curls _________ lbs

Submax-2 Test

HR ______ bpm RPE _______

$\dot{V}O2$ ________ ml/kg/min RER _______

$\dot{V}e$ ________ L/min

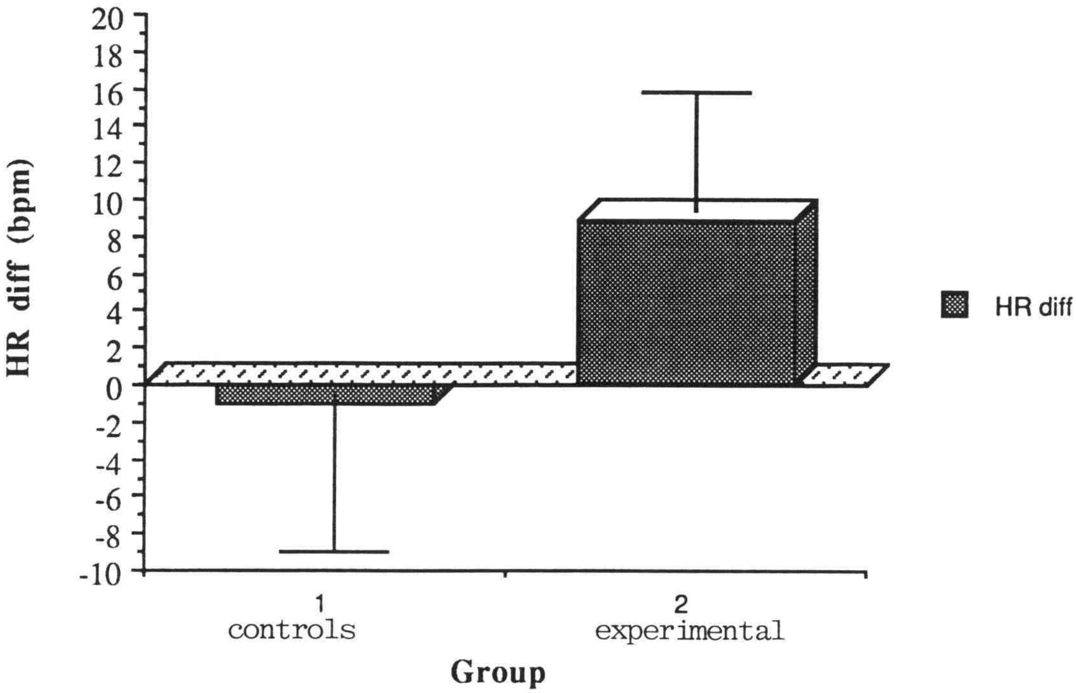
Appendix E

Parameter Data

	Submax Test 1						Submax Test 2				
	(bpm)	($ml/kg^{-1}\ min^{-1}$)	(L/min)				(bpm)	($ml/kg^{-1}\ min^{-1}$)	(L/min)		
Subject	HR	$\dot{V}O2$	$\dot{V}e$	RER	RPE	*	HR	$\dot{V}O2$	$\dot{V}e$	RER	RPE
Control											
01	169	35.00	75.5	.981	13.6	*	176	35.41	73.6	1.01	14.2
05	155	26.39	43.8	.956	13.6	*	158	26.72	46.6	.915	14.8
07	167	34.24	58.5	.973	13.2	*	151	32.58	59.7	.969	14.2
09	151	43.84	77.0	.970	14.6	*	155	44.18	86.5	.968	14.8
10	151	24.34	48.6	1.00	11.6	*	153	25.13	51.9	.946	11.2
12	154	45.47	92.4	.946	13.6	*	148	46.05	92.8	.935	13.2
Experimental											
02	169	36.46	73.9	.990	15.0	*	167	36.26	72.9	.978	15.3
03	148	26.86	57.3	.978	14.0	*	163	26.91	61.0	.936	14.8
04	130	37.95	72.9	.940	12.6	*	143	37.51	74.1	.934	13.3
06	159	31.86	49.3	.948	14.0	*	168	31.72	48.2	.926	13.8
08	154	42.06	60.4	.961	14.4	*	167	46.45	67.1	.942	13.6
11	153	33.37	78.6	1.01	14.2	*	158	39.36	77.0	.971	14.0

Appendix F

HR Mean Differences

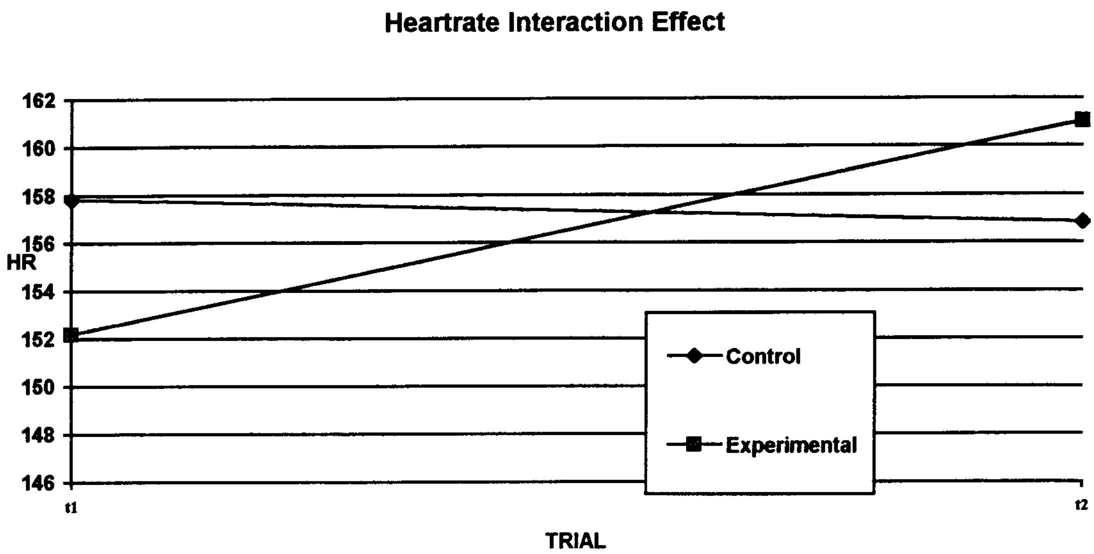


Appendix G

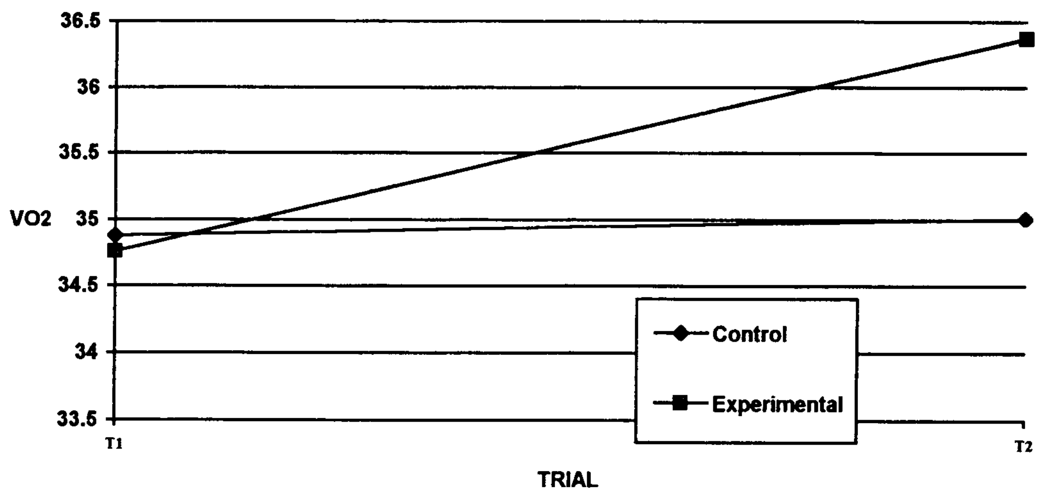
Results Data

Parameter	control trial 1	control trial 2	control mean difference	experimental trial 1	experimental trial 2	experimental mean difference	p-value	power
HR (bpm)	158	157	-1.0	152	161	8.83	.0475*	.68
$\dot{V}O2$ (ml/kg^{-1}min^{-1})	34.88	35.01	0.13	34.76	36.37	1.61	.2502	.31
$\dot{V}e$ (L/min)	66.0	68.5	2.54	65.4	66.7	1.32	.5689	.34
RER	.972	.957	-0.15	.971	.948	-0.32	.5773	.38
RPE	13.4	13.7	.38	14.0	14.1	.10	.4940	.31

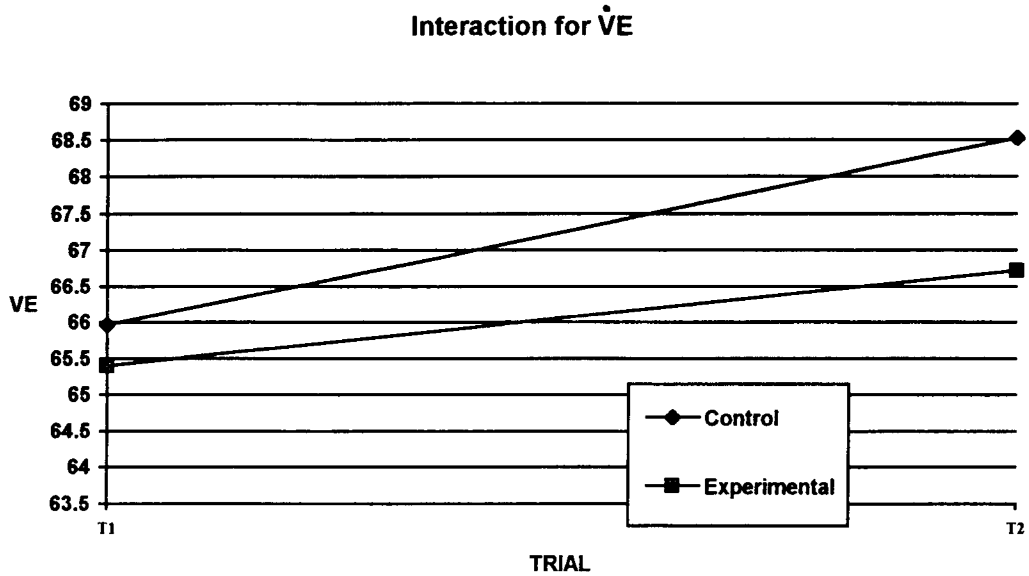
* statistical significance


Heartrate Interaction Effect
162
160
158
156
154
152
150
148
146
HR
t1
t2
TRIAL
Control
Experimental

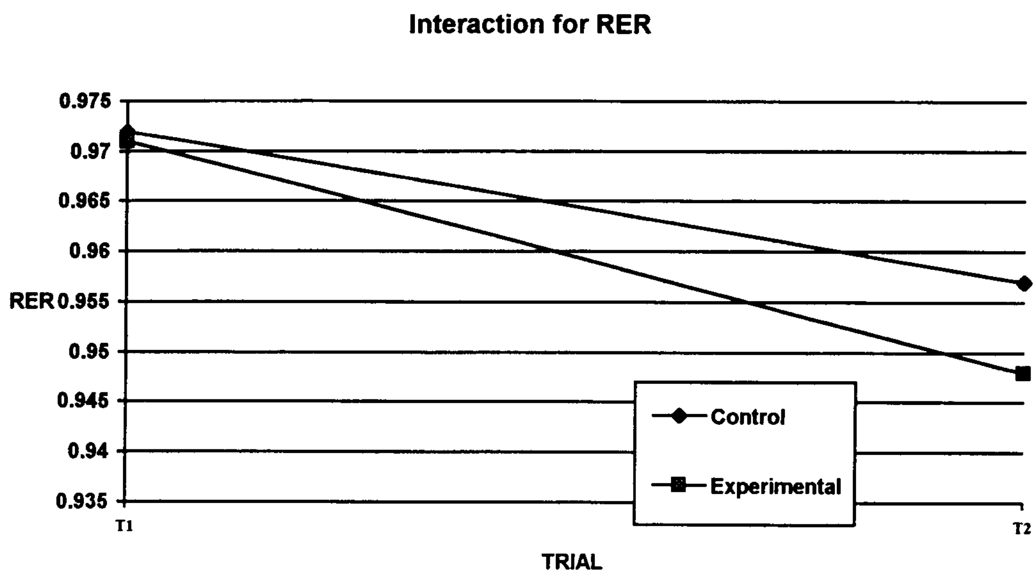
Interaction for V̇O2



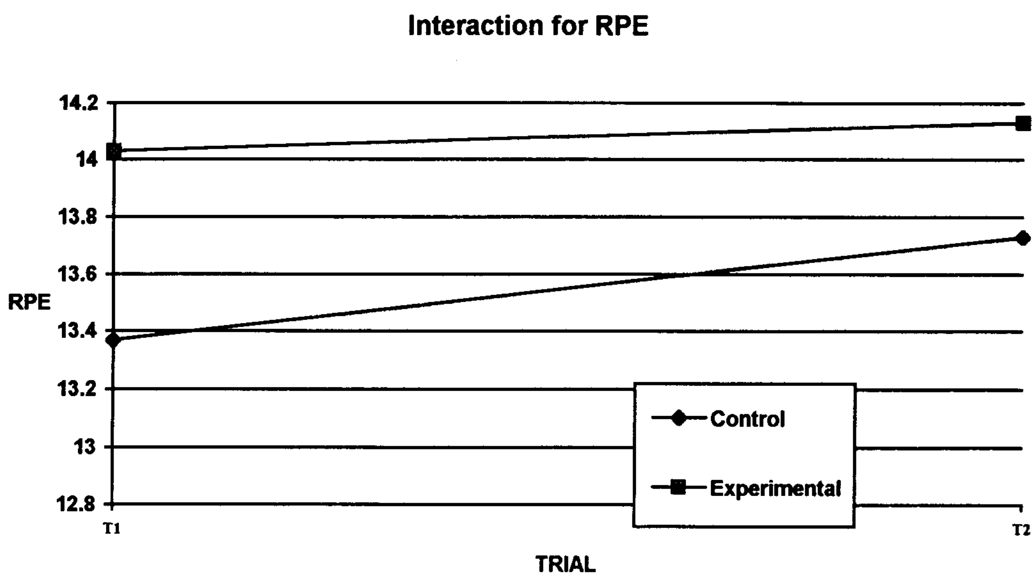
Appendix J


Interaction for V̇E
69
68.5
68
67.5
67
66.5
66
65.5
65
64.5
64
63.5
VE
T1
T2
TRIAL
Control
Experimental

Appendix K


Interaction for RER
0.975
0.97
0.965
0.96
RER 0.955
0.95
0.945
0.94
0.935
T1
T2
TRIAL
Control
Experimental

Appendix L


Interaction for RPE
14.2
14
13.8
13.6
RPE
13.4
13.2
13
12.8
Control
Experimental
T1
T2
TRIAL