ABSTRACT

ABEL, M.G. Effect of heavy resistance training on performance variables in endurance athletes. MS in Human Performance, May 2001, 51pp. (T. McBride).

The purpose of this study was to investigate the effects of 10 weeks of heavy resistance training on performance variables in endurance athletes. Thirteen healthy male endurance athletes (age = 23.6 ± 5.1 yr, ht = 178.8 ± 6.6 cm, wt = 76.0 ± 8.2 kg) were assigned to either a heavy resistance training (HRT) group (N = 7) or a control (N = 6) group. No changes in peak VO_2 or body composition occurred in the HRT group. Significant increases ($p < .05$) in one repetition maximum (1 RM) bench press and squat strength occurred in the HRT group (3.9% and 10% respectively). The HRT group experienced significant reductions ($p < .05$) in blood lactate accumulation at four of the seven treadmill stages. These findings indicate that HRT does not effect peak VO_2 or body composition, but does increase 1 RM strength and may decrease blood lactate accumulation at high running intensities in endurance athletes.

EFFECT OF HEAVY RESISTANCE TRAINING ON PERFORMANCE VARIABLES IN ENDURANCE ATHLETES

A MANUSCRIPT STYLE THESIS PRESENTED

TO

THE GRADUATE FACULTY

UNIVERSITY OF WISCONSIN-LA CROSSE

IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

MASTER OF SCIENCE DEGREE

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MARK G. ABEL

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THESIS FINAL ORAL DEFENSE FORM

Candidate: Mark G. Abel

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Human Performance

The candidate has successfully completed the thesis final oral defense.

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Thesis Committee Chairperson Signature | Date

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Thesis Committee Member Signature | Date

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This thesis is approved by the College of Health, Physical Education, and Recreation.

5/25/01

Associate Dean, College of Health, Physical Education, and Recreation | Date

7-25-01

Director of University Graduate Studies | Date

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INTRODUCTION

Two extremes exist in the physical activity continuum. One extreme is characterized by endurance activities in which high repetitions and low resistance are utilized (i.e., running and cycling). The opposing extreme is inclusive of strength activities of high resistance and low repetitions (i.e., strength training). Endurance activities are effective at increasing maximal oxygen consumption (VO_2 max) without increasing strength (10). In contrast, heavy resistance and low repetition exercises normally increase strength (5), with little or no change in VO_2 max (7,8,12). It is possible that resistance training adaptations may enhance endurance performance (7,8,12). Hence, it has been suggested that fiber type transformations may occur as a result of resistance training (IIB→IIA) (2). The shift toward a type IIA fiber, which has a higher oxidative potential than a type IIB fiber, could influence the metabolic response (6) and enhance endurance performance. Unfortunately, hypertrophy of the trained muscle may inhibit endurance performance by adding body mass and reducing the muscles' oxidative potential per total muscle mass (15). However, strength increases may still occur without muscle hypertrophy, which reflects learning-specific activation and motor unit recruitment patterns (7).

It has been reported that anaerobic power is a critical determinant for race success among cross country-runners who have similar VO_2 values (4), and the fastest long distance runners possess the most powerful muscles (13). For instance, an endurance runner may accumulate greater amounts of lactate when climbing a hill, surging for position, or sprinting at the end of a race, that is, anytime the anaerobic energy system is called upon for ATP production. Hence, resistance training may be an alternate method of decreasing blood lactate accumulation during aerobic exercise.

Resistance training seems to have no evident contraindications toward VO_2 max (7,8,12). Hence, it seems beneficial to supplement endurance training with some type of resistance training. Resistance training is known to increase the force production of the trained muscle. Due to increases in strength, a muscle is able to contract at a lower percent of its peak force. Therefore, running at a given grade should be more efficient with greater strength capabilities. This increase in strength may delay the accumulation of lactic acid (12). Two early studies investigated the relationship between strength and blood lactate accumulation. Kay and Shephard (1969) conducted a study on the relationship of strength and anaerobic threshold. They found a significant correlation (-.58, $p < .01$) between knee extension strength and accumulated lactate after a five minute bicycle ride at 80% of VO_2 max. These data suggest that a stronger individual may have an increased anaerobic threshold. Vodak (1973) investigated the relationship between leg strength and the onset of anaerobic metabolism during continuous bicycling exercise with increasing workloads. Vodak concluded that anaerobic threshold is independent of leg strength.

Hickson, Rosenkoetter, and Brown (1980) stated that, following resistance training, endurance time to exhaustion was significantly increased with cycling (47%) and running (12%) despite no changes in VO_2 max. This was also illustrated by a follow-up resistance training study conducted by Hickson et al. (1988). Therefore, the present study was designed to further examine the effect of heavy resistance training on performance variables in endurance athletes.

METHODS

Subjects

Upon approval by the University of Wisconsin-La Crosse (UW-L) Institutional Review Board, flyers were posted at UW-L Strength Centers requesting volunteers to participate in this study. The subjects were also recruited from UW-L Exercise and Sport Science classes. Subjects signed up for the study and were contacted to schedule a pretesting date. Fifteen male UW-L students volunteered as endurance athletes for this study. Eight subjects performed heavy resistance training (HRT) in addition to their aerobic regimen. The remaining seven subjects served as controls and did not participate in any resistance training over the 10-week training period. However, they did continue their aerobic training regimen. The subjects were between the ages of 19 and 39. All subjects signed an informed consent form (Appendix A) prior to participation, in accordance with University policy.

Study Design

Subjects of the HRT group and the Control group submitted to two testing sessions prior to and immediately after resistance training. One session included VO_2 peak, blood lactate, and body composition measurements. The second session tested maximal muscular strength for horizontal bench press and back squat (one repetition maximum). The muscular strength tests were administered on the first day of the study and immediately following the ten week resistance training period. Both of the pretesting sessions lasted approximately 50 minutes. The sessions were conducted as follows:

Session #1 - As the subjects arrived at the University of Wisconsin-La Crosse Human Performance Laboratory they were asked to read and sign an informed consent form (Appendix A). Questions regarding the consent form or testing procedures were also answered at this time. Height and weight measurements were recorded, and a Polar® heart rate monitor was placed around the subject's chest. This allowed the subject's heart rate to be monitored throughout the peak VO_2 test. A detailed description of blood lactate testing procedures is found in Appendix B. Evaluation of body composition was conducted on a *Dual Energy X-ray Absorptiometer* (DEXA). A separate informed consent form was issued to the subject for this procedure due to the radiation exposure involved.

Session #2 - On the first day of resistance training and immediately following the ten week training period, both groups (HRT and Control) were asked to do maximal muscular strength tests of the upper and lower body. The subjects were encouraged to perform a general warm-up (i.e., stationary bike or running) followed by exercise-specific stretching. A detailed description of the exercise specific warm-up (1 RM Testing) protocol is found in Appendix B.

Peak VO_2 Testing

The peak VO_2 testing protocol was explained in detail to each subject. The subject was informed that the test was completely voluntary and he may terminate the test at any time without penalty. The peak VO_2 test was administered on a treadmill with the Quinton Metabolic Cart® (QMC). Prior to each test, O_2 and CO_2 gases were calibrated. Pneumotach flow calibration of the QMC was performed with a 3-liter calibration syringe, ensuring accurate data collection. Expired air was collected and the O_2 and CO_2 fractions analyzed. The face and mouthpiece were properly placed on the subject. The subject began walking at 1.56 $m \cdot s^{-1}$ and 10% grade for five minutes. This allowed for proper cardiovascular warm-up before the ensuing exercise. The test began as the treadmill velocity was set at 3.13 $m \cdot s^{-1}$ and remained constant for the duration of the test. Initial treadmill grade was set at 0%. The grade was then increased 2.5% every two minutes until completion of the test. The test was terminated and determined to be a peak VO_2 test based on any two of the following criteria: the leveling off of the subject's VO_2, an R-value greater than one, a rating of perceived exertion (RPE) of 19 or 20, or an equal or greater value of the theoretical maximum heart rate (220 – age). Prior to the completion of each two-minute stage, the subject was asked to rank their RPE via Borg's Scale (3) (Appendix C). The subject was asked to step off the treadmill for a blood lactate sample at the completion of each two-minute stage. At this time, RPE, heart rate, and the QMC test time were recorded by the lab assistant. The QMC time was later used to determine the peak VO_2 for each treadmill stage from the QMC 15 second printout. Verbal encouragement was provided throughout the test. Upon completion of the test, subjects walked at 1.34 $m \cdot s^{-1}$ for approximately five minutes or until the subject felt completely recovered.

Blood Sampling

Blood samples were collected by the finger-stick method at rest and immediately following (within 30 seconds) each 2 minute stage of the peak VO_2 / blood lactate test. A five second countdown was given as a cue before the end of each stage. The subjects stopped running by placing their hands on the rail and feet on the outside platform of the treadmill. They immediately held out their left hand, palm up. Any one of the middle fingers was selected to obtain a blood sample. Fingers were alternated for each subsequent blood sample.

To ensure sufficient blood flow, the puncture was made near the fingertip, as opposed to the pad of the finger, with a sterile lancet and Autolet II. New lancets were used for each sample. To avoid contamination, the first drop of blood was wiped away and a 50 microliter (µl) sample was collected in a heparinized capillary tube. Caution was taken to avoid excessive squeezing, or "milking," of the finger as this may cause inaccurate lactate values. The subject resumed running at the new grade 40 seconds after the end of each stage.

Blood Sample Analysis

Using the Yellow Springs Instrument® (YSI) Lactate Analyzer Pipet, 25 µl of blood was extracted from the capillary tube and expelled into a microcentifuge tube containing a 50 µl NaF – Triton buffer solution. The prepared samples were immediately shaken for approximately five seconds to allow mixing.

Twenty-five µl of the blood sample was extracted from the micro-centrifuge tube and expelled into the lactate analyzer for measurement of blood lactate concentration. The lactate analyzer was zeroed and calibrated to a 5.0 $mmol/L^{-1}$ lactate standard before and after four samples were analyzed.

Body Composition

The body composition test was performed using an FDA-approved Dual Energy X-ray Absorptiometry machine (Prodigy®, Lunar Corporation, Madison, Wisconsin). Total amount of fat free mass (bone, organ, and muscle tissue in grams), fat mass (fat tissue in grams) and percent body fat were measured in the entire body as well as isolating the lower extremities. The subjects were asked to lay face up on a padded table for a total of ten minutes while the scanner arm passed over them. The scanner arm did not enclose or touch the subjects. Subjects were exposed to minimal radiation within an acceptable range as provided by the Wisconsin Department of Health and Family Services (DHFS) [Chapter HSS 157.03(1)(g)].

1 RM Testing

The exercise selected to test upper body muscular strength was the horizontal bench press. The criteria used to measure the horizontal bench press included: eccentrically lowering the bar in a slow and controlled manner, touching the bar to the chest and pressing the bar up concentrically until the elbows were fully extended. (A visual aid of the bench press technique performed is found in Appendix D.)

The exercise selected to test lower body muscular strength was the back squat. The criteria used to measure the back squat included: eccentrically lowering the bar in a slow and controlled manner until the thighs were parallel to the floor. This criteria was established by placing a piece of surgical tubing behind and perpendicular to the subject. The surgical tubing was set so that the subject's hamstrings would contact the tubing when the thighs were parallel to the floor. The subject then pushed concentrically until the knees were fully extended. If the subject felt he could lift a greater amount of weight, resistance was raised accordingly until he failed to complete a "successful" lift. (A visual aid of the back squat technique performed is found in Appendix E.)

Resistance Training Protocol

In the HRT group, strength training was performed three days per week. Seventy-two hours rest was given for recovery between strength training sessions of the same muscle group. Three sets of six repetitions were performed at approximately 85% of the 1 RM for each exercise. Three minutes of rest was given between sets. A sample of a single upper and lower body resistance training workout is listed below (tables 1 and 2). A detailed description of the HRT protocol is found in Appendix F.

Table 1. Sample of Upper Body HRT Protocol

Exercise	**Sets**	**Repetitions**	**Rest Period**
Bench Press	3	6	3 minutes
Bent-Over Row	3	6	3 minutes
Shoulder Press	3	6	3 minutes
Biceps Curl	3	6	3 minutes
Triceps Pushdown	3	6	3 minutes

Table 2. Sample of Lower Body HRT Protocol

Exercise	**Sets**	**Repetitions**	**Rest Period**
Back Squat	3	6	3 minutes
Smith Mach. Lunge	3	6	3 minutes
Prone Leg Curl	3	6	3 minutes
Calf Raise	3	6	3 minutes

Aerobic activity was to remain unchanged throughout the 10-week training period in all subjects. An Aerobic Activity Log was distributed to each of the subjects to establish exercise consistency. The log identified mode, duration, frequency, and intensity of each bout of aerobic exercise performed. A detailed description of the Aerobic Activity Log is found in Appendix G.

<u>Statistical Analysis</u>

Basic descriptive statistics were used to summarize the characteristics of the subjects. Within-group comparisons of dependent variables were made using paired sample t-tests. Levels of significance were set at the $p < .05$ level.

RESULTS

Of the fifteen subjects originally enrolled, only thirteen completed the study and were included in the analysis of the results. It should be noted that subject number two was dropped from the HRT group because of a large drop in peak VO_2, due to inactivity. Subject number nine of the Control group was also excused from the study due to an inability to complete the tests because of injury. Table 3 describes the subjects' characteristics.

Table 3. General Characteristics of the Subjects

Group	n	Age	Height (cm)	Body Mass (kg)
HRT	N = 7	22.13 ± 1.69	178.2 ± 6.4	74.85 ± 7.61
Control	N = 6	25.52 ± 7.04	179.5 ± 7.5	77.39 ± 9.33

It should be noted that the Control group had a larger standard deviation in age due to a single outlier. This did not affect the outcome of the results.

<u>Strength Changes</u>

The results for the 1 RM testing are presented in Table 4. The HRT group experienced a significant increase of 10.06% ($p < .05$) in maximal squat strength.

The Control group did not significantly increase maximal squat strength. The HRT group significantly increased maximal bench press strength by 3.88% ($p < .05$). Meanwhile, the Control group experienced no change in maximal bench press strength.

Table 4. 1 RM Testing of Squat and Bench Press (kg)

Group	Squat Pretest	Squat Posttest	Bench Press Pretest	Bench Press Posttest
HRT	116.23 ± 17.43	127.92 ± 20.61*	100.33 ± 15.99	104.22 ± 13.15*
Control	97.73 ± 18.01	99.24 ± 16.24	83.33 ± 15.79	83.33 ± 13.99

*Indicates significant change ($p < .05$) from pretest.

Peak Oxygen Consumption

Peak oxygen consumption for the HRT group was 58.13 ± 1.22 $ml\cdot kg\cdot min^{-1}$ and 55.84 ± 2.74 $ml\cdot kg\cdot min^{-1}$ for pretest and posttest respectively. Similarly, peak oxygen consumption in the Control group was 56.68 ± 5.96 $ml\cdot kg\cdot min^{-1}$ and 53.65 ± 7.56 $ml\cdot kg\cdot min^{-1}$ pretest and posttest, respectively. No significant changes in peak VO_2 occurred in either group.

Blood Lactate Response

The HRT group (Figure 1) experienced a significant decrease in blood lactate accumulation from pretest to posttest in four of the six treadmill stages completed. The significant decreases in blood lactate accumulation occurred at the following stages: grade 1, grade 2, grade 4, and grade 6. The Control group

(Figure 2) had a significant decrease in blood lactate accumulation from pretest to posttest in three of the five stages of the treadmill test. The significant decreases occurred at grade 1, grade 3, and grade 4. A significant decrease in blood lactate accumulation from pretest to posttest also occurred at rest.

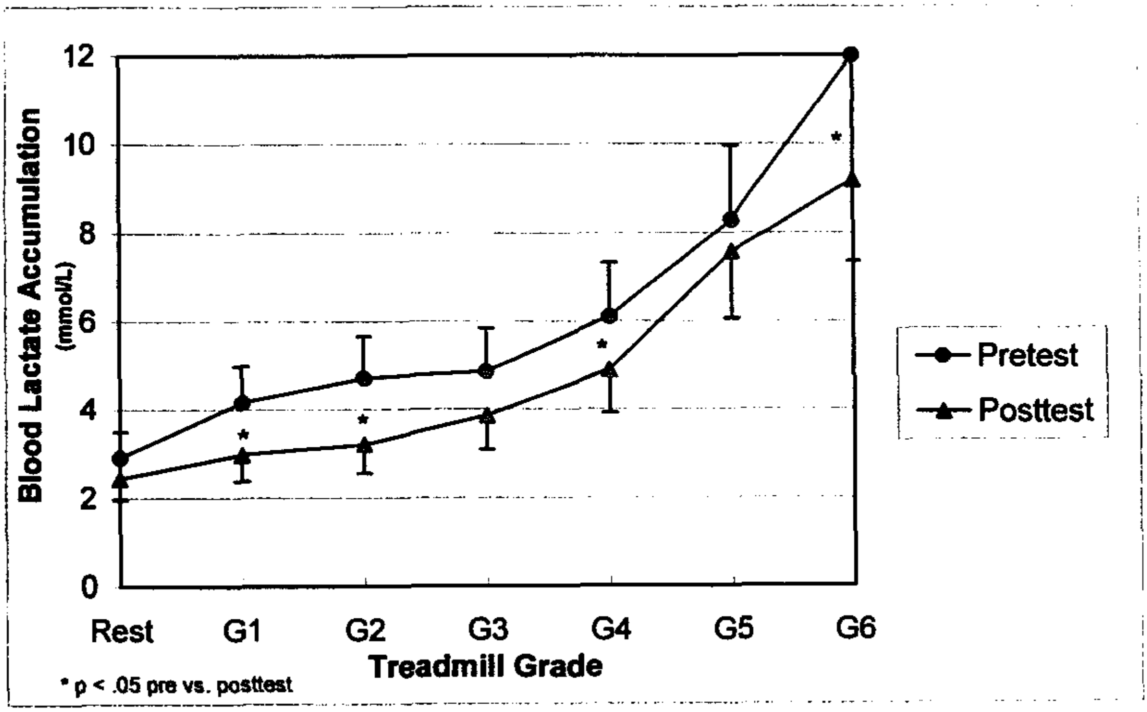

Figure 1: Blood lactate accumulation for the HRT group.

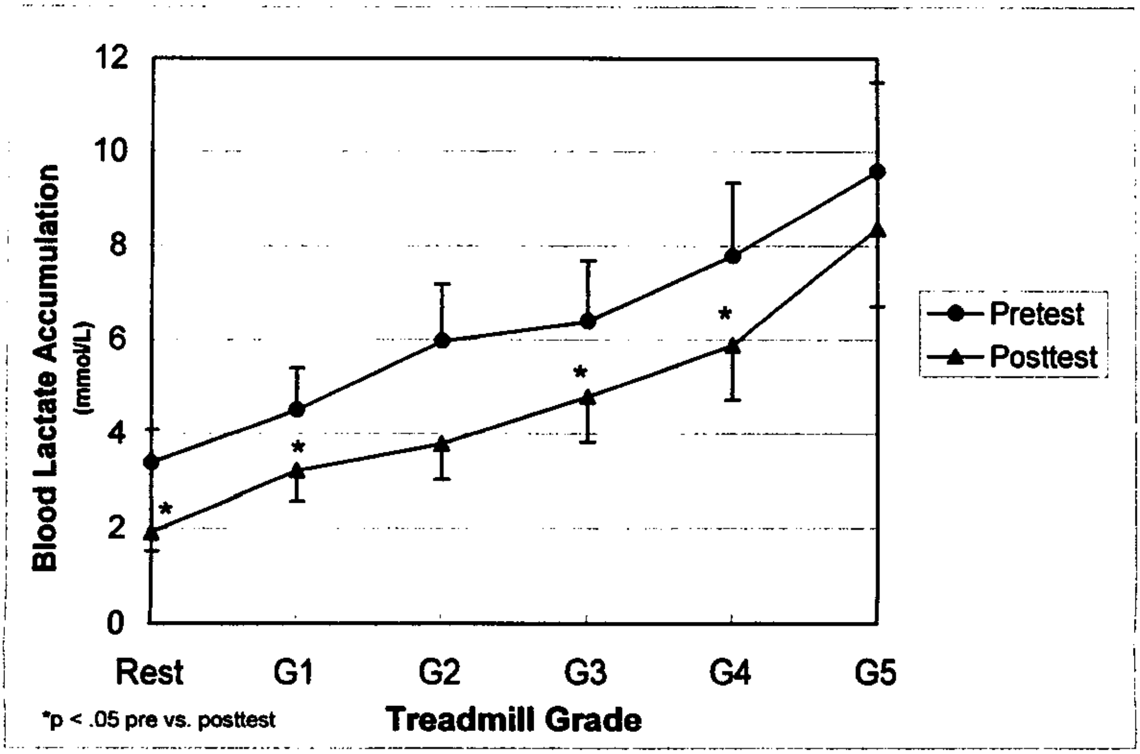

Figure 2: Blood lactate accumulation for the Control group.

Body Composition

Body composition was measured to determine fat free mass, fat mass, and percent body fat. The HRT group did not experience a significant change in fat free mass, fat mass, or percent body fat. The Control group experienced a very small but significant increase in percent body fat, with no change in fat free mass or fat mass. Body composition changes were also investigated in the lower extremities. Neither the HRT group nor the Control group exhibited a significant change in fat free mass, fat mass, or percent body fat in the lower extremities. Tables 5, 6, and 7 describe the subjects' body composition characteristics.

Table 5. Average Mass and Fat Free Mass Measurements (kg)

Group	Mass Pretest	Mass Posttest	Fat Free Mass Pretest	Fat Free Mass Posttest
HRT	74.84 ± 7.61	76.43 ± 6.87	63.28 ± 5.67	64.21 ± 5.31
Control	77.39 ± 9.33	77.46 ± 9.09	62.51 ± 5.60	62.07 ± 5.48

Table 6. Average Fat Mass (kg) and Percent Body Fat Measurements

Group	Fat Mass Pretest	Fat Mass Posttest	Percent Body Fat Pretest	Percent Body Fat Posttest
HRT	8.21 ± 3.81	8.87 ± 3.78	10.83 ± 4.48	11.46 ± 4.17
Control	11.23 ± 5.48	11.78 ± 5.45	14.22 ± 5.60	14.88 ± 5.52*

*Indicates significant change ($p < .05$) from pretest.

Table 7. Average Lower Extremity Body Composition Measurements (kg)

Group	Fat Free Mass Pretest	Fat Free Mass Posttest	Fat Mass Pretest	Fat Mass Posttest
HRT	21.58 ± 2.19	22.07 ± 1.90	2.95 ± 1.14	3.08 ± 1.08
Control	21.65 ± 2.35	21.53 ± 2.52	3.74 ± 1.43	3.86 ± 1.21

DISCUSSION

The primary finding of this investigation is that heavy resistance training is effective for increases in strength without significant changes in body composition or peak VO_2 levels in endurance runners. In addition, heavy resistance training may decrease the blood lactate response at high aerobic workloads.

The HRT group experienced a significant increase in mean maximal squat strength as well as mean maximal bench press strength. These values are similar to those found by other investigators (1,2). Increases in muscular strength occurred without an increase in fat free mass, which may indicate an increase in neuromuscular function. Hickson et al. (1988) suggested such an observation may reflect learning specific activation and motor unit recruitment patterns rather than intramuscular biochemical alterations.

Hickson, Rosenkoetter, and Brown (1980) conducted a strength training study in which 3-5 sets of five repetitions were used. Weight training frequency occurred five days per week. They found an increase in endurance capacity without an increase in VO_2 max. Specifically, subjects significantly increased bicycle time to exhaustion by 47% and treadmill time to exhaustion by 12%. No explanation could be given for these results.

In the present study, peak oxygen consumption for the HRT group remained constant. Other literature has supported the finding that strength training does not negatively affect VO_2 max when aerobic training is held constant (7-9).

A decrease in lactate accumulation at relative workloads was found in both the HRT group and Control group, except at near maximal intensities. At near maximal intensities the HRT group experienced a significant decrease in blood lactate accumulation while the Control group did not. This trend was seen in two studies involving cycling. Marcinik et al. (1991) found a significant reduction in plasma lactate concentration at relative intensities ranging from 55% to 75% of peak VO_2 as a result of strength training. Goreham et al. (1999) found a significant decrease in blood lactate accumulation immediately following exercise to exhaustion. Because blood flow during contraction is known to be related to the relative force of contraction (16), less occlusion of blood flow should result from the reduced percentage of peak force required per stride after training.

No significant correlation was found when percent gain in squat strength was correlated to percent change in maximum blood lactate levels. The lack of correlation may be due to test specificity. That is, the squat strength test may not closely mimic treadmill running. Likewise, a study conducted by Vodak et al. (1973) found no significant relationships between leg strength and anaerobic threshold even when testing specificity was accounted for. This study used an incremental bicycle ergometer test to determine anaerobic threshold. Anaerobic threshold was defined as the time during the bicycle test at which there was a nonlinear increase in ventilation (VE) and volume of carbon dioxide (VCO_2) expired along with an abrupt increase in the respiration quotient (R) and fraction of expired oxygen (F_{EO2}). Leg strength was measured on an isokinetic leg training device as well as during bicycling using a friction bicycle ergometer adapted to an electromechanical dynamometer.

In contrast, Kay and Shephard (1969) found a significant negative correlation ($r = -.58 \pm .20$, $p < .01$) between isometric leg strength and blood lactate accumulation. It should be noted, however, that Kay and Shephard (1969) performed their study on a bicycle ergometer with a single blood lactate measurement two minutes following five minutes of exercise at 80% of VO_2 max. The strength correlation involved handgrip strength as well as isometric (120°) leg extension strength. Kay and Shephard (1969) felt that the appearance of blood lactate was due to the occlusion of blood vessels in working muscles that occurred at a given percent of the individual's maximal isometric strength. At this given percent, blood flow was shunted and anaerobic metabolism began. The authors suggested that strong individuals exerted a lower percentage of maximal strength at each standardized work level on the bicycle. Therefore, these subjects would take longer to accumulate a substantial amount of blood lactate. Conflicting evidence by Pirnay, Marechal, Radermecker and Petit (1972) has shown progressive increases in blood flow to the quadriceps muscles during exercise advancing towards maximal exertion.

In the current study, it should be noted that the Control group significantly decreased blood lactate accumulation at rest and during three of the five treadmill stages. These results may be related to subject overtraining prior to the pretest followed by a period of detraining. This explanation is supported by a decrease (insignificant) in peak oxygen consumption as well as a significant increase in percent body fat. It is also possible that the Control group was more active prior to the blood lactate testing session, resulting in an increased baseline blood sample. Finally, a lack of familarization with the testing protocol may have caused a significant decrease in blood lactate accumulation from pre to posttest.

Based on the present study, endurance performance at near maximal intensities was enhanced by HRT. That is, blood lactate accumulation at the last stage for the HRT group significantly decreased during the posttest. These results contradict those found by Hickson, Rosenkoetter, and Brown (1980), as well as Hickson et al. (1988). Both of these investigations found no change in blood lactate accumulation following exercise to exhaustion. It should be noted, however, that Hickson et al. (1988) extracted blood five minutes post exercise via the antecubital vein. Hickson et al. (1980) drew blood immediately following treadmill exercise from the antecubital vein. Nonetheless, the previously mentioned studies displayed an improvement in endurance performance not related to an increase in maximal VO_2 levels. Hickson et al. (1980) could not explain the mechanism for an increase in endurance performance due to a subsequent increase in maximal strength. Although, the possibility of a neuromuscular response to strength training and subsequent alterations in motor unit recruitment patterns was suggested (8).

In closing, it appears the increase in 1 RM strength in the present study was elicited primarily from alterations in neuromuscular responses. It may be possible that the increase in maximal strength contributed to the decreased blood lactate accumulation at near maximal (VO_2) intensities in the HRT group. In conjunction with this effect, no change in peak VO_2 or body composition occurred. Thus, implementing a heavy resistance training protocol may be beneficial to endurance performance. These adaptations demonstrate the need for further research regarding neuromuscular responses to resistance training coupled with endurance training.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT FOR THE EFFECT OF HEAVY RESISTANCE TRAINING ON PERFORMANCE VARIABLES IN ENDURANCE ATHLETES
Principal Investigator: Mark Abel

I ______________________________ give my informed consent as a volunteer to be in a study to determine the effect of heavy resistance training on lactate threshold and muscular strength. I consent to presentation and publication or other dissemination of study results as long as the information is confidential and disguised so that no personal identification can be made. I have been informed that although a record will be kept of my having participated in the study, all experimental data collected from my participation will be identified by number only.

I have been informed that I will report to the Human Performance Laboratory in Mitchell Hall (room 225), at the University of Wisconsin-La Crosse. I will be required to complete a Graded Exercise Test for maximal oxygen consumption, a blood lactate test, and an upper and lower body muscular strength test. The Graded Exercise Test and blood lactate test will be completed on the treadmill. The Graded Exercise Test ($VO_{2\,max}$) is a measure of the body's ability to utilize and transport oxygen throughout the body during exercise. The test will involve wearing a mouthpiece and headgear, which may cause dry-mouth during the test, and possibly jaw and gum soreness following the test.

While performing the Graded Exercise Test, the possibility does exist for the occurrence of adverse conditions (i.e. dizziness, shortness of breath, abnormal blood pressures, fainting, chest pain, etc.). I have been informed that I will feel some level of fatigue at the end of the test. If any abnormal signs or symptoms occur during the testing, the test will be immediately terminated.

A Graded Exercise Test will require that I run until volitional exhaustion. The test administrator will continue to encourage me to continue running until I give an indication to end the test. The actual test may take 15-25 minutes to complete, depending on maximal VO_2 levels reached. Additional time will be required for a resting blood sample for lactate, warm-up, stretching, and a cool-down (approximately 5 minutes each), for a total of 45 minutes.

I have been informed that a blood sample will be taken by finger prick method at rest, and immediately following each 2-minute stage of the test. Between stages I will stop briefly (one minute) for blood sampling, then resume running at the new grade. Blood will be extracted from the tip of my left index, middle, or ring finger. For each blood sample, alternating fingers will be used and the location of the prick changed to prevent excessive trauma. To ensure my safety, sterile methods and equipment will be used for each sample taken. Clean alcohol wipes and lancets will be used for each sample. A small bruise may develop as a result of repeated finger pricks.

I have been informed that my body composition (percent fat and lean body mass) will be determined using an FDA-approved scanning machine (Prodigy, Lunar Corp., Madison, WI). I have been informed that I will be asked to lay face up, on a padded table for about a total of 10 minutes while the scanner arm passes over me, however, the scanner will not enclose me or touch me. I have been informed that I will be exposed to minimal radiation which is within an acceptable range as provided by the Wisconsin Department of Health and Family Services (DHFS) [Chapter HSS 157.03(1)(g)].

I have been informed that I will be required to perform muscular strength test. A one repetition maximum test for the horizontal bench press and the back squat will be used. I have been informed that a series of parallel back squats are to be completed until my one repetition maximum has been determined. For safety purposes, individuals will serve as spotters to assist me if help is needed. Though highly unlikely, muscle strains, pulled muscles, joint tenderness, delayed onset of muscle soreness, or other soft tissue injuries may occur.

I have been informed that these tests involve strenuous exertion. I have no previous existing condition. These conditions would include: heart disease, lung/respiratory conditions, high blood pressure, prone to fainting or seizures, and contagious diseases possibly transmitted through blood. I have been informed that these tests will be terminated if any abnormalities are observed. I have been informed that I may terminate the tests at any time for any reason stated and/or unstated.

The training period will include 10 weeks of resistance training at a rate of three days per week. Upper and lower body resistance training will alternate on Monday, Wednesday, and Friday. The resistance training protocol will include three sets of six repetitions at approximately 85% of the individuals 1 RM. Approximately five exercises will be selected for the upper body and five exercises will be selected for the lower body.

I will personally benefit as a result of participating in this study by: gaining knowledge of my $VO_{2\,max}$, blood lactate threshold, and muscular strength (1 RM). Subjects in the heavy resistance-training group will be provided with 10 weeks of supervision via a Certified Strength and Conditioning Specialist (CSCS) in a given resistance training program. Controls will be offered an orientation to a resistance-training program at the conclusion of the study.

As a result of the proposed research project I will gain knowledge of whether heavy resistance training may benefit endurance athletes. This information can aid athletes, coaches, and the entire field of exercise science.

Questions regarding the protection of human subjects may be addressed to Dr. Garth Tymeson, Chair, UW-La Crosse Institutional Review Board, (608) 785-8155. Questions regarding study procedures may be directed to Mark Abel, (608) 782-0938, or Dr. Travis McBride (Thesis Chair), (608) 785-6546.

Participation in all testing procedures and the training study itself is strictly voluntary. There is no charge for participation in this study. The refusal to participate or the decision to discontinue participation (at any time) will involve no penalty or loss of benefits. I have been informed that it is my responsibility to provide costs for any needed medical care as a result of an accident occurring due to my participation in this study.

The tests will be conducted by Mark Abel, a graduate student in the Human Performance Program at the University of Wisconsin-La Crosse. The tests will not be supervised by a medical doctor. Therefore I understand that I must assume total responsibility for any adverse effects that may occur.

I read and have been informed of the procedures as described and/or explained to me. I have been fully advised of the nature of the tests and possibly the risks involved, of which I assume voluntarily. In signing this consent, I certify that I am agreeing to the above statements freely and without reservation. I have been informed that I may withdraw my participation at any time.

Signed:______________________________

Date:__________________

Witness:_____________________________

APPENDIX B

TESTING INFORMATION / RESULTS FORMS

Name ____________________ Group __________________

Lab Pre-Test Results

VO_2 Results	VO_2	RPE	HR
0% Grade			
2.5% Grade			
5.0% Grade			
7.5% Grade			
10.0% Grade			
12.5% Grade			

Lactate Results

At Rest

____

0% Grade

____

2.5% Grade

____

5.0% Grade

____

7.5% Grade

____

10.0% Grade

____

12.5% Grade

____

ONE REPETITION MAXIMUM TESTING
BENCH PRESS

Name:______________________
Date:____________

Estimated 1RM:______________

Warm-Up Sets:

Set 1 (0.4* est 1RM):___________ 8 Repetitions
2 minutes rest

Set 2 (0.6* est 1RM):___________ 4 Repetitions
2 minutes rest

Set 3 (0.8* est 1RM):___________ 2 Repetitions
3 minutes rest

Set 4 (0.9* est 1RM):___________ 1 Repetition
4 minutes rest

Set 5 (1RM): ___________
4 minutes rest

Set 6 (1RM): ___________
4 minutes rest

Set 7 (1RM): ___________

<u>Estimated 1RM's – untrained or moderately trained</u>

	Women	Men
Bench Press	.5-.75 BW	1-1.5 BW
Squat	11.25 BW	1.75-2.25 BW

ONE REPETITION MAXIMUM TESTING
BACK SQUAT

Name:______________________
Date:____________

Estimated 1RM:______________

Warm-Up Sets:
Set 1 (0.4* est 1RM):___________ 8 Repetitions
2 minutes rest

Set 2 (0.6* est 1RM):___________ 4 Repetitions
2 minutes rest

Set 3 (0.8* est 1RM):___________ 2 Repetitions
3 minutes rest

Set 4 (0.9* est 1RM):___________ 1 Repetition
4 minutes rest

Set 5 (1RM): ___________
4 minutes rest

Set 6 (1RM): ___________
4 minutes rest

Set 7 (1RM): ___________

<u>Estimated 1RM's – untrained or moderately trained</u>

	Women	Men
Bench Press	.5-.75 BW	1-1.5 BW
Squat	11.25 BW	1.75-2.25 BW

APPENDIX C

RATING OF PERCEIVED EXERTION SCALE

Ratings of Perceived Exertion Scale

6

7 Very, very light

8

9 Very light

10

11 Fairly light

12

13 Somewhat hard

14

15 Hard

16

17 Very hard

18

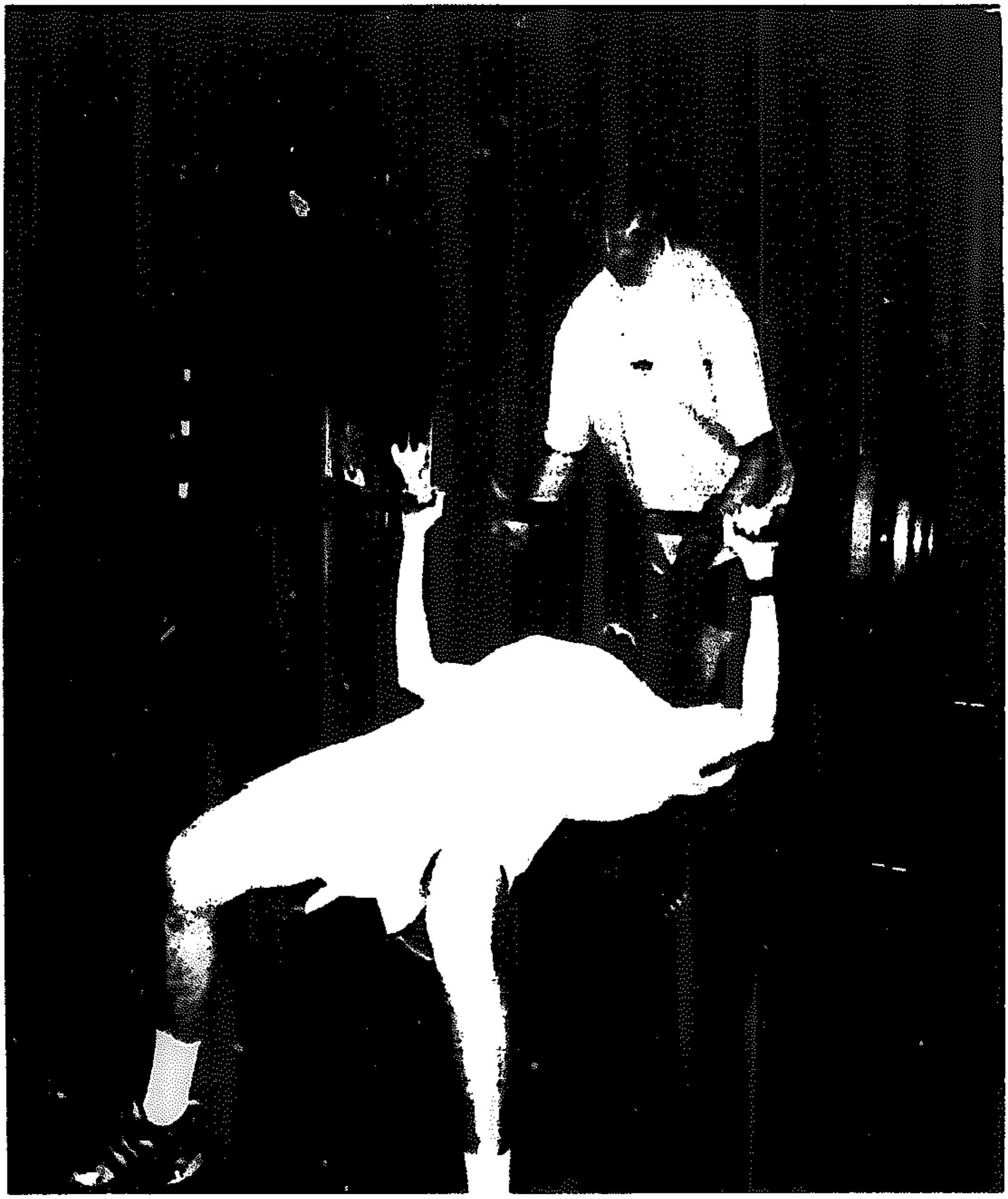
19 Very, very hard

20

Borg, B. Perceived exertion: a note on "history" and methods. Med. Sci. Sports 5:90-93, 1973.

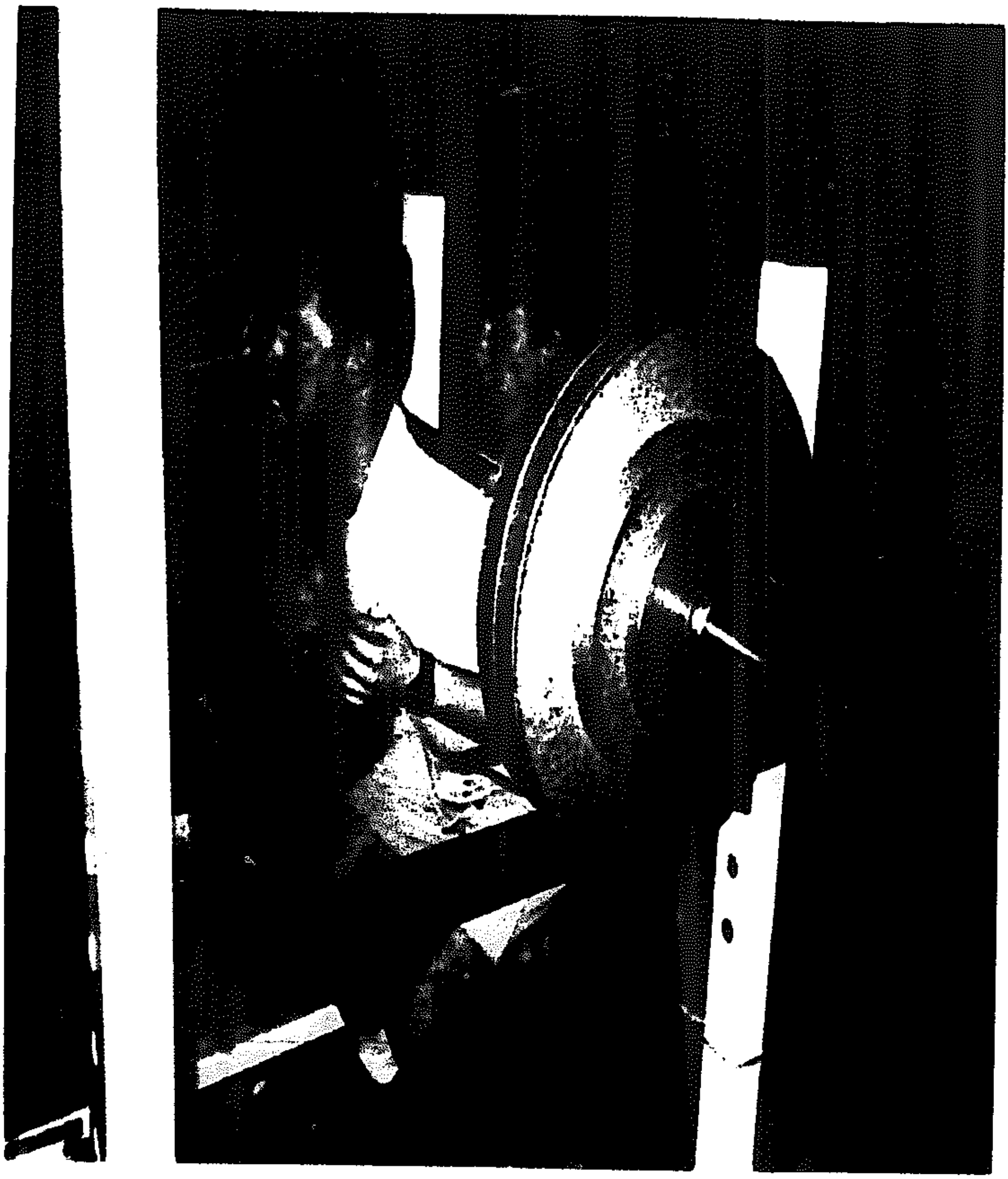
APPENDIX D

PICTURE OF SUBJECT: BENCH PRESS STRENGTH TEST



APPENDIX E

PICTURE OF SUBJECT: SQUAT STRENGTH TEST



APPENDIX F

PROTOCOL FOR HEAVY RESISTANCE TRAINING PROGRAM

Heavy Resistance Training Program

Three workouts were performed each week. The workouts were conducted on Monday, Wednesday and Friday at the University of Wisconsin-La Crosse Strength Center. This workout frequency allowed a minimum of 72 hours recovery per muscle group. Subjects were instructed as to which exercises to perform and of the correct technique to be used. For safety, each subject was paired with a partner to assist the lift if needed. Proper spotting technique was also reviewed.

The heavy resistance training program consisted of the following:
3 sets of 6 repetitions per exercise
3 minutes of rest between sets
3-5 minutes of rest between exercises

The exercises selected for the 10-week training period included:

Upper Body

Weeks: 1- 3	Weeks: 4-7	Weeks: 8-10
Bench Press	Incline DB Chest Press	Bench Press
Bent-Over Row	Bench Press	Incline DB Chest Press
DB Shoulder Press	Bent-Over Row	Bent-Over Row
DB Biceps Curl	Military Press	Military Press
Triceps Pushdown	Barbell Biceps Curl	Barbell Biceps Curl
	Supine Triceps Ext.	Supine Triceps Ext.

Lower Body

Weeks: 1-3	Weeks: 4-7	Weeks: 8-10
Back Squat	Back Squat	Back Squat
Smith Machine Lunge	Step-Up	Step-Up
Prone Leg Curl	Deadlift	Stiff Leg Deadlift
Calf Raise	Stiff Leg Deadlift	Calf Raise
	Calf Raise	

All exercises were performed at 85% of the subjects 1 RM. If six repetitions were easily reached, the subject was asked to increase the weight to the next higher available weight (i.e. Bench press: If the subject lifted 125 lb six times relatively easily, move up to 130 lb on the following set).

APPENDIX G

AEROBIC ACTIVITY LOG

Aerobic Activity Log

Name ______________________________

Please record the type of aerobic activity being performed, duration and relative intensity level (Intensity level is based on the scale below).
Example: Running / 30 minutes / RPE = 12

Borg Scale[3]: Rating of Perceived Exertion (RPE)

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Average Week for the past 2 months

____
____
____
____
____
____

Week of September 17th-23rd

____
____
____
____
____
____
____

APPENDIX H

REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

Introduction

The purpose of this study was to determine the effect of heavy resistance training on performance variables in endurance athletes. This chapter provides a review of lactate formation, lactate removal, effects of lactic acid on muscle contractile function, exercise-induced blood lactate accumulations, and effects of strength training on endurance performance.

Lactate Formation

The appearance of lactate in muscle and blood has been suggested to be related to lack of molecular oxygen in the contracting muscles. A close relationship has been demonstrated between occurrence of lactate in contracting muscles and low oxygen saturation values in venous effluent from contracting muscles (15). In the absence of oxygen, creatine phosphate is regenerated by anaerobic pathways using energy derived from the conversion of glycogen to glucose to lactate. The overall glycogen breakdown in the cytoplasm can be summarized as:

$$(1/n\ (C_6H_{10}O_5)_n + 2NAD^+ + 3ADP + 3P_i\ \ (2NADH + 2H^+ + 3ATP + 2(C_3H_4O_3))$$

However, pyruvate is in equilibrium with lactate as illustrated below.

$$(\text{Pyruvate} + NADH + H^+ \leftrightarrow \text{lactate} + NAD^+)$$

Thus, in the absence of oxygen, formation of lactate prevents an excessive accumulation of pyruvate and restores the NAD^+ needed to help forward the breakdown of glycogen. According to classical theory, the blood lactate does not rise except with time lags in circulatory adaptation at the beginning of exercise and if the steady rate of working exceeds the overall potential of the body for aerobic energy release (22).

The blood concentration of lactate depends on several factors. These factors include the rate of diffusion of lactate from the muscle fiber into the blood stream, the total volume of muscle that is functioning anaerobically, and the total circulating blood volume (24).

Lactate Removal

Reconstitution of the lactic acid system means mainly the removal of the excess lactic acid that has accumulated in all the fluids of the body. This is especially important because lactic acid causes extreme fatigue. When adequate amounts of energy are available from oxidative metabolism, removal of lactic acid is achieved in two ways. First, a small portion of lactic acid is converted back into pyruvic acid and then metabolized oxidatively by all the body tissues. Second, the remaining lactic acid is reconverted into glucose mainly in the liver, and the glucose in turn is used to replenish the glycogen stores of the muscles (8).

Effects of Lactic Acid on Muscle Contractile Function

Compared with aerobic exercise training, strength training appears to be ineffective for increasing VO_2 max (13). It is clear that one must perform repetitive and rhythmic large muscle group exercises that tax the aerobic glycolytic system and the oxidative phosphorylation system to increase VO_2 max.

Maximal oxygen uptake measures the ability of the body to transport oxygen from ambient air to the working muscles, and it is one of the more important determinants of endurance performance (4). VO_2 max may be a good measure of aerobic capacity but it may not be the optimal predictor of endurance performance.

In contrast, plasma lactate parameters provide better indices of endurance performance than peak VO_2 (2). Blood lactate concentrations may help define an optimal level of endurance training that lies just below an intensity at which substantial amounts of lactate accumulate in the blood stream (26). It is possible that exercising blood lactate concentrations may be altered without affecting the status of VO_2 max. An evaluation of training may show that long-term endurance is improving despite a stagnation of gains in oxygen transport. This change reflects the development of anaerobic mechanisms (10).

Sherwood (2001) has stated that in near maximal contractions the blood vessels that course through the muscle are compressed and almost closed by the powerful contraction, severely limiting the oxygen available to the muscle fibers. In addition, Shephard (1992) has indicated that the training of muscular endurance can influence performance positively in several ways. As muscles become stronger they contract at a smaller fraction of their maximal voluntary force. Perfusion thus occurs more readily, and a given effort can be sustained without recourse to the anaerobic activity that would cause an accumulation of lactate and, subsequently, a decrease of muscle force.

A decrease in force of contraction seems to occur in response to a local accumulation of lactate, with an inhibition of glycolysis and a failure of ATP regeneration in the active muscle fibers (28). The overall loss of muscle force thus depends on the proportion of muscle fibers in which lactate concentration has exceeded the limiting value for continued contractile function (22).

The mechanism responsible for a decrease in muscle contractile force on the cellular level begins with the breakdown of lactic acid to lactate and hydrogen ions. This causes a decrease in the calcium released from the sarcoplasmic reticulum. Thus, less calcium can bind to troponin leading to a decrease in calcium – troponin saturation. It has also been speculated that increased [H^+] concentration may interfere with the formation of cross-bridges in the muscle cell by competing with the calcium molecule on the binding sites of troponin (20). In addition, it may inhibit key enzymes in the energy-producing pathways or excitation-contraction coupling process (25).

In prolonged exercise there is a preferential recruitment of muscle fibers that now has also been demonstrated in running (6). This selective recruitment theory is based on the observation that motor units are composed of the same fiber types that are innervated by motor neurons with different thresholds (11).

Likewise, several investigators have stated that due to a varying perfusion of the local capillary supply and differences in local intramuscular enzyme concentrations one type of fiber within a given muscle may be functioning aerobically while another must resort to anaerobic metabolism. Lactate can thus diffuse from the anaerobically contracting fibers and be metabolized by fibers that are still operating aerobically. Moreover, the nature of the physical activity undertaken may be such that one muscle fiber group is operating at a larger fraction of its maximal force, and therefore lacks adequate perfusion, while a second muscle group that is contracting less vigorously is not only able to function aerobically, but can also metabolize lactate originating from the first muscle group (19,22).

Exercise-Induced Blood Lactate Accumulations

Blood lactate has been described as the appearance and/or presence of lactate in the blood. Lactate concentration increases at a particular exercise intensity, which varies among individuals, and continues to increase as the work rate increases. During exercise, when energy demands are high, the conversion of pyruvate to lactate in the working muscle increases due to the increased rate of glycolysis. As lactate concentration increases, it begins to diffuse into the blood, thus, the appearance of blood lactate. Many other complex mechanisms interact and contribute to the appearance of blood lactate (17).

It has been stated that individuals can exercise to a certain critical intensity with little or no accumulation of lactate in the plasma. However, when this critical intensity is passed, lactate begins to accumulate exponentially (21). Lactic acid is preferentially produced by fast twitch fibers and thus, a higher percent of slow twitch fibers may lead to a lower lactate accumulation at a given pace. This finding may be due to greater capacity for glycolysis (5). Increasing levels of blood lactate may interfere with free fatty acid utilization (14), and thus progressively reduce the capacity of the blood to utilize fat as an energy substrate. An increase in lactate threshold should delay this inhibition and result in a glycogen sparing effect (3) and therefore enhance endurance performance.

Effects of Strength Training On Endurance Performance

For instance, Hickson et al. (1980) found that following resistance training, endurance time to exhaustion significantly increased while cycling (47%) and while running (12%) despite no changes in VO_2 max. They suggested that the improvements in endurance performance from the strength training may be related to increases in muscular strength or power. Similar conclusions were made from a follow-up study (12).

In Marcinik et al. (1991), eighteen healthy males volunteered to participate in a resistance training study. Lactate threshold decreased (12%) following strength training. A significant decrease in blood lactate concentration also occurred between 55% and 75% of the subjects' peak VO_2. Peak VO_2 did not change significantly after training. It is evident from this study th: resistance training caused the decrease in lactate accumulation of relative workloads when compared in pretest and posttest.

Marcinik et al. (1991) also reported this increased strength and lactate threshold were both associated with extended endurance time but the reason for the improved performance is unknown. However, Hickson et al. (1988) conducted a resistance training study relative to cycling endurance. They attributed the improved endurance performance from strength training to changes in fiber type recruitment. They proposed that a greater rate of slow twitch and reduced rate of fast twitch fiber recruitment during constant-load exercise could result from increased quadriceps strength. It is possible that this could lead to an improved time to exhaustion by reducing the percentage of peak tension required for each push of the pedal. It is also possible that this factor could explain the reduced plasma lactate levels during submaximal cycling exercise observed in Marcinik et al. (1991).

Likewise, Goreham et al. (1999) found a significant ($p < .05$) decrease in lactate accumulation (38.9 ± 8.5 vs. 24.4 ± 6.1 mmol/kg dry weight) following a significant increase in lower body strength. The high resistance training protocol was inclusive of 12-weeks of resistance training using 3 sets of 6-8 repetitions per exercise.

Resistance training may also improve short-term treadmill performance, leg strength, and anaerobic power in moderately trained endurance athletes.

Data from one study, for example, indicated that the addition of resistance training exercises to an endurance training regimen improves leg strength by 30% and short term treadmill performance by 13% (12). Treadmill performance required maximal work rates that resulted in exhaustion within 5-8 minutes.

A strength training program (where the goal is strength) is characterized by high resistance, near maximal muscular contractions extended over a small number of repetitions, with a full recovery period between each set (27). Heavy resistance training, with loads of approximately six repetitions, has been shown to lead to significant increases in most aspects of muscular function (1).

Despite the known gains in strength with heavy resistance training, most endurance athletes who are reluctant to resistance train believe that it will cause them to hypertrophy to a level that will hinder their endurance performance due to gains in muscle mass and body weight. However, not all resistance training programs produce the same level of hypertrophy. Typically, significant hypertrophy is the result of programs utilizing moderate to high intensities (6-12 RM), high volumes (> 3 sets) and short rest periods between sets (< 1.5 minutes), with a large variety of exercises (16). In addition, a strength-emphasis program (≤ 6 RM, > 2 min rest, 3 sets) has been shown to greatly improve strength without significant levels of muscle hypertrophy (9). Further investigation is necessary to determine what effect heavy resistance training may have on increasing strength and the associated changes in body composition in endurance athletes, which could affect endurance performance.

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