A COMPARISON OF SELECTED PHYSIOLOGICAL VARIABLES IN RESPONSE TO TREADMILL ERGOMETRY AND ELLIPTICAL CROSSTRAINING EXERCISE, WHILE EXERCISING AT THE LACTATE THRESHOLD

By

THOMAS S ALTENA

Bachelor of Arts in Physical Education
Dordt College
Sioux Center, Iowa
1996

Masters of Arts in Education
University of South Dakota
Vermillion, South Dakota
1998

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF EDUCATION
August, 2001

A COMPARISON OF SELECTED PHYSIOLOGICAL

VARIABLES IN RESPONSE TO TREADMILL

ERGOMETRY AND ELLIPTICAL

CROSSTRAINING EXERCISE,

WHILE EXERCISING AT THE

LACTATE THRESHOLD

Thesis Approved:

Thesis Advisor

Dean of the Graduate College

ACKNOWLEDGEMENTS

A special thanks is for my wife, Heidi. She has been and is my rock. Throughout this research, she has displayed patience and kindness greater than I deserved, and greater faith in my abilities than I could muster. To her I rededicate the rest of my life.

This research would not have been possible without the diligent assistance, dedication, vision, and expertise of my committee members. Thank you to my dissertation and research advisor, Dr. Frank A. Kulling, my doctoral committee chair, Dr. Steven W. Edwards, for their dedication and vision to see this project from start to finish. To Dr. Betty M. Edgley, and to Dr. James A. Webster, also committee members, thank you to them for their efforts and their encouragement. Because of this committee's commitment to quality, their vision, their genuine attitudes of love for life, and their sense of humor, this research was completed. In addition, thank you also to Dr. Bert H. Jacobson for his assistance in equipment acquisition for this research.

Without the research subjects, this research could not have been completed. Thank you to the 18 young men who willingly allowed me to use their bodies for this research.

Thank you to the Wellness Center at Oklahoma State University and, specifically, thank you to Robin Purdie R.N. who willingly allowed this research to be conducted in the exercise lab and assisted in defraying research costs.

Finally, thank you to Jim Birrell of PRECOR, Inc. of Bothell, WA. Without their support through supplying an elliptical trainer, this research would not have been possible.

TABLE OF CONTENTS

Chapter Page

Chapter Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

Exercise Modalities and Elicited Physiologic Responses

A wide variety of exercise modalities are accessible for fitness programs and exercise testing. Exercise machines can vary in the way they support the body and in the use of different amounts of muscle mass to execute the exercise. Historically, the modalities of exercise studied have been treadmill walking or running, cycle ergometry, arm-crank ergometry, stepping ergometry, rowing ergometry and various forms of simulated cross-country skiing (Kravits, Robergs, Heyward, Wagner, Powers, 1997). In 1994 the Miller Walker Transport was introduced as a new concept in exercise modalities. This early elliptical prototype appeared to be a hybrid of walking or running on a treadmill, cycle ergometry, and stair stepping. Bates & Mercer (1994) stated the elliptical exercise modality features an elliptically-shaped stride which insures zero impact activity and a range of intensities including those which can achieve cardiorespiratory conditioning. These are speculated reasons that might increase the exercise enjoyment of the participant. Subjects can change the ramp incline, rate of stepping or RPM, adjusting the resistance, and can use either a forward or reverse motion in order to mimic stepping, cycling and/or treadmill. These mechanical adjustments allow subjects to target specific lower-body muscles in order to create cross-training effects. Adjustment of these variables allow the individual to simulate a version of other exercise modalities such as walking, running, bicycling, cross-country skiing and stair stepping (Bates et al., 1994).

A variety of elliptical exercise machines have followed the Miller Walker Transport. Different types of elliptical trainers are produced by many different manufacturers. PRECOR, Inc. has marketed the EFX (Elliptical Fitness Crosstrainer) since 1996. Bates (1995) and Bates et al. (1994) report the Miller Walker Transport elicits varying physiological responses to exercise, while eliminating impact to the body typically associated with walking or running on a treadmill. Previous research on the elliptical exercise has evaluated electromyography (EMG), heart rate (HR), oxygen uptake (VO_2), and rating of perceived exertion (RPE). The results of early elliptical research stated physiologic differences were observed between different mechanical workloads of the elliptical exercise modality and other exercise modalities (Bates, 1995; and Bates et al., 1994). The research contained in this document compared elicited physiologic responses observed in both motorized treadmill exercise and elliptical exercise, while exercising at the lactate threshold (LT).

Cardiorespiratory Exercise and Exercise Modalities

The health benefits of participating in regular, continuous, cardiorespiratory exercise is not a topic that requires debate. The American College of Sports Medicine (ACSM) supports a physically active lifestyle consisting of cardiorespiratory exercise at low-to-moderate levels of intensity. This exercise intensity reduces the risk of various chronic and degenerative illnesses and diseases (Franklin, 2000). However, to improve cardiorespiratory fitness the mode of exercise should utilize large amounts of muscle mass during exercise and should be performed for long periods of time and should be at a moderate-to-vigorous level of exercise intensity. Different modalities of exercise, because of the exerciser's body position, offer potentially varying degrees of energy expenditure. Total energy expenditure induced by exercise is an important consideration in both exercise prescription and weight loss. Various exercise modalities may elicit different cardiorespiratory and metabolic responses due to the chosen type of exercise (Thomas, Feiock, & Araujo, 1989). Brooks, Fahey, White, & Baldwin (2000) stated the optimal exercise intensity, in order to gain the greatest health and cardiorespiratory benefits, should occur at the LT, which occurs at approximately 50-60% maximal oxygen uptake (VO_2max) in most apparently healthy subjects (Brooks et al., 2000)

Purpose Statement

The purpose of this study was to compare oxygen uptake (VO_2), blood lactate concentration (BLC), heart rate (HR), oxygen-pulse (O_2-pulse), and perceived exertion (RPE) in response to treadmill and elliptical ergometry, among aerobically trained, college-age males, while exercising at the lactate threshold.

Hypotheses

All of the following null hypotheses will be tested at the $p<0.05$ level:

HO_1: There will be no significant difference in blood lactate accumulation in treadmill ergometry compared to the elliptical fitness crosstrainer, when exercising at the LT.

HO_2: There will be no significant difference in VO_2 in treadmill ergometry compared to the elliptical fitness crosstrainer, when exercising at the LT.

HO_3: There will be no significant difference in RPE in treadmill ergometry compared to the elliptical fitness crosstrainer, when exercising at the LT.

HO_4: There will be no significant difference in O_2-pulse in treadmill ergometry compared to the elliptical fitness crosstrainer, when exercising at the LT.

HO_5: There will be no significant difference in heart rate in treadmill ergometry compared to the elliptical fitness crosstrainer when exercising at the LT.

Assumptions

For the purposes of this study, the following assumptions were accepted for this research:

1) Subjects, as instructed, will refrain from ingesting food, alcohol, tobacco, drugs, or caffeine at a minimum of three hours prior to each test.
2) Subjects, as instructed, will refrain from extensive and intense exercise 48-hours prior to each exercise testing session.

3) Subjects, as instructed, will be honest and able in interpreting the Borg's Scale of Perceived Exertion.

4) Subjects, as instructed, will be honest in answering the questions on the Physical Activity Readiness Questionnaire (PAR-Q) concerning their personal health history and exercise habits.

5) Subjects, as instructed, will maintain an activity level that reflects their activity level prior to being selected to be in the study. Subjects will engage in no new exercise habits or make drastic changes in exercise modalities, frequency, duration, or intensity throughout the duration of the study.

Delimitations

This study is delimited by the following:

1) All subjects were volunteer, college-age males at a large Midwestern university.

2) All subjects fell into the parameters of being "healthy", as deemed by the PAR-Q.

3) To be included in the study, all subjects must have a predicted VO_2max of no less than 42.22 $ml \cdot kg \cdot min^{-1}$.

4) Subjects were also exercising aerobically at least three sessions per week for a total accumulation of at least 90 minutes per week.

5) All subjects were required practice/acclimation time with the treadmill and the elliptical modalities. They were also required two sessions with both

modalities with practice sessions lasting a minimum of 15 minutes per session.

6) Subjects were allowed additional practice sessions to improve competency on either or both exercise modalities. Competency was defined as the subject's ability to exercise without holding onto the support bars for balance.

7) Knowledge of the mechanical functioning and elicited physiological responses concerning the elliptical exercise apparatus were gained through a series of unreported experimental pilot tests.

8) During equivalent exercise intensities, VO_2 was assessed with the metabolic cart and was also the criteria in which the mechanical workload at the LT was assessed, adjusted and maintained.

Limitations

This study was limited by the following:

1) Maximal oxygen consumption will be predicted by extrapolating sub-maximal results to predicted maximal HR.

2) There is no known research using the elliptical exercise modality that has assessed BLC or long-duration exercise using a calculated caloric expenditure as a research parameter.

Study Design

This is a comparative study that examined potential differences between treadmill ergometry and the elliptical exercise modality, while exercising at the LT. Data collected from each subject in both modalities were compared as a group and not individually. The dependent variables: BLC, VO_2, HR, O_2-pulse, and RPE were assessed systematically throughout each exercise test conducted. These data were used to assess the metabolic demand and physiological markers resulting from exercise with the treadmill in comparison to those elicited by the elliptical fitness crosstrainer.

Definition of Terms

Blood Lactate Concentration (BLC) refers to the amount of lactate present in the blood (Brooks et al., 2000).

An Ergometer is an apparatus (treadmill, cycle ergometer, etc.) used for measuring the amount of work done by a human or animal subject (Robergs & Roberts, 1997).

Glycolysis is the reactions of anaerobic metabolism that does not require the presence of oxygen to produce ATP (Robergs et al., 1997).

A Graded Exercise Test (GXT) is a multi-stage exercise test, usually conducted with a treadmill or cycle ergometer, in which exercise intensity is progressively increased through levels, which eventually results in the subject reaching a predetermined level or voluntary fatigue (Robergs et al., 1997).

Group 1 or Type I Activities are activities that can be readily maintained at a constant intensity and individual variation in energy expenditure is low (Franklin, 2000).

Group 2 or Type II Activities are activities in which the rate of energy expenditure is highly related to skill (Franklin, 2000).

Group 3 or Type III Activities are activities where both skill and intensity of exercise are highly variable (Franklin, 2000).

Indirect Calorimetry is the determination of heat production of an oxidative reaction by measuring the uptake of oxygen and/or the liberation of carbon dioxide and nitrogen excretion (Thomas, 1970).

A Kilocalorie (kcal) is unit of heat content or energy. This is the amount of heat necessary to raise 1000 grams of water from 14.5°C to 15.5°C (Robergs et al., 1997).

Lactate is an organic compound formed from pyruvic acid during anaerobic respiration (Saldin, & Van Wynsberghe, 1998).

The Lactate Threshold (LT) is defined as the highest exercise intensity or intensity of VO_2 that is not associated with an elevation of BLC above the pre-exercise level, or BLC of less than 1 $mmol \bullet L^{-1}$ (McArdle, Katch & Katch, 1996).

Maximal Lactate Steady State (MLSS) occurs when a subject is exercising at the highest external power at which a balance exists between the appearance of lactate in the blood and the rate at which the removal of lactate occurs from the blood during constant-load exercise (Beneke, Hutler & Leithanhauser, 2000).

Maximal Oxygen Uptake (VO_2max) is the maximal rate of oxygen consumption by the body (Robergs et al., 1997).

A Metabolic Cart is an apparatus that analyzes expired gases utilizing computerized sensors that measure the air content for oxygen, carbon dioxide, and evaluate air volume, RQ, and minute ventilations (Brooks et al., 2000).

The Miller Walker Transport is an exercise modality that is a hybrid of walking or running on a treadmill, cycle ergometry, and stair stepping that features an elliptically-shaped stride and zero impact to joints. Exercise intensity can be adjusted by changing the ramp incline, stepping rate, adjusting the resistance, and can use either a forward or reverse motion (Bates et al., 1994).

Oxygen-pulse (O_2-pulse) is the volume of oxygen consumed by the body per heart beat (Dirckx, J. H., 1997). This is calculated by:

$$\frac{\text{Relative VO2}}{\text{Heart Rate}} = \text{O2-pulse}$$

The Rate of Perceived Exertion (RPE) or The Borg's Scale of RPE is a subjective numerical scale rating the intensity of a given exercise based on how the subject feels in relation to physiological stress (Borg, 1982).

The Respiratory Exchange Ratio (RER) or Respiratory Quotient (RQ) is the ratio of carbon dioxide production to oxygen consumption. Often utilized to indirectly determine the contribution of carbohydrates to energy production (Robergs et al., 1997).

Exercise Steady State is the point when an exercise intensity is attained, and the total ATP demand from muscle contraction is met through oxidative phosphorylation. Therefore, during steady state exercise, ATP formation with oxygen has reached a plateau and metabolic acidosis does not develop (Robergs et al., 1997).

VO_2 is the expression of oxygen consumption/utilization (Robergs et al., 1997).

Nomenclature

ml•kg•min^{-1} represents the amount of oxygen consumed by the body in milliliters per kilogram of body weight per minute of exercise at a given intensity (Robergs et al., 1997).

mmol•L represents millimoles per liter of fluid (Robergs et al., 1997).

MPH represents miles per hour in horizontal ground speed (Robergs et al., 1997).

% represents the percent grade of incline.

CHAPTER II

REVIEW OF LITERATURE

Chapter II is the review of literature for this document. The following pages have previous research pertaining to the unique physiologic responses elicited by various exercise modalities. Also, previous research with the elliptical exercise modality will be included. The following pages also provide information about the methodologies implemented in previous research, which influenced the rationale and design of this study.

Physiologic Responses Elicited in Exercise Ergometry

Limited research has focused on sub-maximal metabolic responses to different exercise modalities. Some comparisons have been made during short, incremental exercise tests in which the duration of the tests lasted 10 minutes or less. Many of the shorter tests were conducted as a maximal graded exercise test. In contrast, there are few studies that have involved exercise modality comparisons during steady-state exercise. Modality comparisons have been made with treadmill walking and running, stationary cycling, simulated cross-country skiing, arm-crank ergometry, and rowing (Zeni, Hoffman, & Clifford, 1996; Thomas, Ziogas, Smith, Zhang, & Londeree 1995; Thomas et al., 1989; Miles, Critz, Knowlton, 1980; and Faulkner, Roberts, Elk, & Conway, 1971).

During exercise modality research, a variety of physiologic measures have been implemented for the assessment of exercise intensity. Thomas et al. (1995) used VO_2 to equate exercise intensity across six different modalities and compared the percentage of VO_2max with a rating of RPE. Kravits et al. (1997) used self-selected exercise intensities which could also be interpreted as RPE, which was what Zeni et al. (1996) used in their modality research. Thomas et al. (1989) used a percentage of the subject's age-dependent maximal heart rate. These different researchers used these variables in order to create an equal workload and/or exercise intensity. The goal of all their research was similar in that they desired to compare the associated physiologic responses unique to each exercise modality (Kravitz et al., 1997).

The LT provides the most complete picture of the physiologic stress and metabolic demand required for exercise. Using maximal HR or VO_2max alone do not take into account the biochemical demand during exercise (Welman, 1995; Yoshida, 1987; Henrizte, Welman, Schurrer, & Barlow, 1985; and Yoshida, 1984). Welman (1995), Yoshida et al. (1987), Henrizte et al. (1985) advocate BLC as a valid physiological marker for exercise prescription. When prescribing exercise for cardiorespiratory fitness, subjects should be exercising at or near the lactate threshold (LT). The use of the LT for exercise-intensity is based on the premise that it serves as a physiologic marker of exercise intensity in reference to VO_2max (Welman, 1995; Yoshida et al., 1987; and Henrizte et al., 1985).

Cardiorespiratory Variables and Caloric Expenditure

Thomas et al. (1989) compared the VO_2 response of subjects at similar percentages of their age-dependent maximal heart rates. Exercise sessions were 60 minutes. The desire for the research was to compare energy expenditure among four different exercise modalities. Thomas et al. (1989) reported no significant difference in VO_2 or energy expenditure comparing stationary cycling, rowing, simulated cross-country skiing or treadmill jogging. In other research by Thomas et al. (1995), six modalities of exercise were evaluated for 20 continuous minutes, using RPE and percentage of VO_2max to equate exercise intensity. The first bout of sub-maximal exercise, the exercise intensity on each apparatus was equated by the patient's RPE of 14. The second bout of exercise used 60% of the subject's VO_2max (Thomas et al., 1995).

The results of the VO_2max testing observed treadmill jogging to be significantly ($p<0.05$) greater, with respect to energy expenditure, than all other exercise modalities. Simulated cross-country skiing and stepping were greater in VO_2max and energy expenditure compared to rowing. The results of the 20-minute steady state test, where an RPE rating of 14 was used, indicated the VO_2 of treadmill jogging was significantly ($p<0.05$) higher than the VO_2 of cycling, stepping, simulated cross-country skiing, shuffle skiing, and rowing. Stepping VO_2 was significantly ($p<0.05$) greater than cycling. No other VO_2 comparisons reached statistical significance. Mean HR was significantly ($p<0.05$) different among the exercise modalities. Treadmill jogging elicited the greatest mean HR in order to achieve the RPE rating of 14. Treadmill HR was significantly ($p<0.05$) greater than cycling, simulated cross-country skiing, shuffle skiing, and rowing.

No statistical significance was observed between treadmill and stepping. No significance in HR was discovered between cycling, shuffle skiing, simulated cross-country skiing or rowing. When exercise intensity was equated by bouts at 60% mode-specific VO_2max, mean HR was significantly ($p<0.05$) different compared among the exercise modalities, which also affected O_2-pulse. Oxygen-pulse was significantly ($p<0.05$) higher during treadmill compared to shuffle skiing, cycling and rowing exercises. No statistical significance was achieved between simulated cross-country skiing or stepping. During the 60% mode-specific VO_2max tests, RPE was significantly ($p<0.05$) different only between treadmill and cycling. No significance in RPE was observed between simulated cross-country skiing, shuffle skiing, and stepping (Thomas, et al., 1995).

Significantly ($p<0.05$) different physiologic responses have been observed when comparing cycle ergometry and treadmill exercise, when exercising at the same VO_2. Miles et al. (1980) compared the elicited physiologic responses from the cycle ergometer and the treadmill. Two tests, one maximal and one sub-maximal, were conducted with each modality of exercise. The highest VO_2max recorded of either modality was used for the comparison of both modalities at 30, 60, and 80 percent of subject's VO_2max (Miles et al., 1980).

Miles et al. (1980) observed a significant ($p<0.05$) difference in VO_2max between treadmill and cycle ergometry. The VO_2max was eight percent greater in treadmill exercise. These results are in agreement with early research conducted by McKay, & Banister, (1976) where maximal HR in treadmill exercise was significantly ($p<0.05$) higher than cycle ergometry. Mean heart rate in the sub-maximal VO_2 intensities observed no statistical differences between cycle ergometry and treadmill exercise (Miles et al., 1980).

Kravitz et al. (1997) evaluated cardiovascular and metabolic responses to self-selected exercise intensities in 1) stationary bicycling (lower body, and non-weight bearing), an 2) aerobic rider (upper body and lower body, and non-weight bearing), 3) treadmill (lower body, and weight bearing), and 4) simulated cross-country skiing (upper body and lower body, and weight bearing). All subjects participated in a treadmill test of VO_2max. Before data collection began, subjects needed to demonstrate exercise proficiency in each exercise modality being evaluated (Kravitz et al., 1997).

Each testing procedure included a five-minute warm-up. After the warm-up, subjects exercised at a steady pace for a total of 20 minutes beyond the warm-up time at an intensity that was individually selected by the subject. The self-selected exercise intensity was implemented to simulate a typical aerobic exercise session if the person was exercising recreationally and was not in a scientific study. Variables monitored during the exercise tests were: 1) VO_2, 2) HR, 3) energy expenditure, and 4) RPE. Variable measurements were recorded every four minutes (Kravitz et al., 1997).

Results of Kravitz et al. (1997) observed VO_2 to be significantly ($p<0.05$) different across exercise modes. The VO_2 was greatest in treadmill exercise than in all other modes of exercise. Also the VO_2 was significantly ($p<0.05$) greater in simulated cross-country skiing than cycling and aerobic riding. The VO_2 of cycling was significantly ($p<0.05$) greater than aerobic riding. In the case of total energy expenditure, a significant ($p<0.05$) difference observed in exercise modalities. Results revealed energy expenditure to be significantly ($p<0.05$) greatest in treadmill exercise compared to all other modalities. No significant differences in caloric expenditure were observed between the other exercise modalities. Average HR during exercise revealed significant ($p<0.05$) differences among the modalities. Average HR was similar with treadmill and simulated cross-country skiing, but there was no significant difference observed between them. These two modalities had significantly ($p<0.05$) higher HR than cycling and aerobic riding. The average HR during cycling and aerobic riding were both significantly ($p<0.05$) lower than treadmill and simulated cross-country skiing, with aerobic riding having a significantly ($p<0.05$) lower HR than cycling (Kravitz et al., 1997).

Thomas et al. (1995) also reported a substantially higher sub-maximal VO_2 during treadmill jogging, in comparison to other modalities of exercise when using RPE to equate exercise intensities across all modalities. However, Thomas et al. (1989) observed no statistical differences ($p<0.05$) in VO_2 when comparing cycling, treadmill, rowing, and simulated cross-country skiing when using 65% maximal HR (Thomas et al., 1989).

Based on the 1989 study, no significant ($p<0.05$) differences were observed in energy expenditure between cycling, treadmill, rowing, and simulated cross-country skiing during the prolonged, low-intensity exercise (Thomas et al., 1989). In contrast, Kravitz et al. (1997) suggests sub-maximal energy expenditure is not simply a reflection of the muscle mass necessary for exercise, but is affected by the significantly ($p<0.05$) higher VO_2 for the weight bearing exercise modalities studied. Furthermore, Kravitz et al. (1997) stated if muscle mass was the only determining factor, simulated cross-country skiing and aerobic riding should elicit a greater VO_2, because they employ greater muscle mass than treadmill exercise (Kravitz et al., 1997).

Kravitz et al. (1997) explained the dilemma of VO_2 differences observed between exercise modalities. When superimposing arm exercise onto leg exercise, blood flow to the exercising lower extremities is reduced and the availability of oxygen to the leg muscles is compromised. This phenomenon occurs when the exercise load of the upper extremities is at least 30 percent of the total workload (Toner, Glickman, & McArdle, 1990). In addition, the amount of available blood is not sufficient to support this intensity of simultaneous exercise of upper and lower body movement. A proposed mechanism for the compromised VO_2max is due to the inability of the blood to maximally perfuse a large contracting muscle mass, thereby causing reductions in peak muscle blood flow (Kravitz et al., 1997; Rowell, 1988). Furthermore, the increased sympathetic neural drive, resultant of upper body exercise, restricts the venous return, which may inhibit cardiac output (Kravitz et al., 1997).

In this multiple exercise modality comparison, Kravitz et al. (1997) concluded that subjects chose higher exercise intensities in weight-bearing exercise in comparison to non-weight-bearing modalities, like cycling and rowing. Weight bearing exercise, like treadmill walking or running, consumes more oxygen and expends more calories than non-weight-bearing modalities. In addition, observations of Kravitz et al. (1997) might indicate the amount of exercising muscle may not truly produce a greater demand for energy expenditure in all exercise modalities. Kravitz et al. (1997) demonstrated that simulated cross-country skiing might not require as much muscle recruitment as actual corss-country skiing (Kravitz et al., 1997, and Thomas et al., 1995).

Zeni et al. (1996) explored physiologic responses elicited by different indoor exercise modalities. Thirteen subjects (8-men, 5-women) volunteered for this research.

Each subject underwent a four-week habituation phase in order to become familiar with the six indoor exercise machines used in the study: 1) the Airdyne cycle, a 2) simulated cross-country skiing machine, a 3) cycle ergometer, a 4) rowing ergometer, a 5) stair stepping ergometer, and a 6) treadmill for walking or running. Each subject viewed videotape, which demonstrated efficient execution of each exercise modality and received individual coaching on proper techniques specifically for the simulated cross-country skiing and rowing modalities. This habituation phase was also used as a period to teach subjects how to properly use the Borg's scale of RPE (Zeni et al., 1996).

Prior to testing, subjects were required to practice exercising with each exercise modality twice per week for a minimum of 15 minutes per session. During these sessions, five minutes were performed at each subject's self-selected work rate. Work rates corresponded to the Borg's Scale of RPE at levels of 11 ("fairly light"), 13 ("somewhat hard"), and 15 ("hard"). During the third and fourth weeks of habituation, a metabolic cart was used to measure VO_2. This was done to assess the ability of each subject to select an exercise workload corresponding to a specific RPE, according to their fitness level (Zeni et al., 1996).

Following the habituation period, the order of exercise modality and testing was randomized for each subject. All exercise tests were conducted at approximately the same time of day. In order to create an equivalent VO_2 across different exercise modalities, adjustments were made in mechanical exercise intensity by changing the resistance on the rowing ergometer, cycle ergometer, and stair stepping ergometer. Treadmill horizontal ground speed was adjusted to maintain the corresponding VO_2 to the subject's self-selected exercising RPE, but the grade was set at 1.6% and did not change at any time during the testing (Zeni et al., 1996).

Before each exercise test, subjects completed a five-minute warm-up corresponding to an RPE of 11 for each subject. After warm-up, the subject rested for two minutes. The fifteen-minute exercise test consisted of three stages, each stage lasting five minutes, with each stage having a work rate corresponding to RPE ratings of 11, 13, and 15. Oxygen consumption was recorded during the final minute of each stage. Heart rate was continuously monitored with a Polar Vantage XL heart rate monitor and was also recorded at the end of each stage (Zeni et al., 1996).

Using RPE to establish an equivalent work rate, Zeni et al. (1996) observed caloric expenditure to be significantly ($p<0.05$) different between the six modalities of exercise. Caloric expenditure was calculated using the VO_2 of each subject. At RPE levels of 13 and 15, treadmill walking and running elicited significantly ($p<0.001$) higher VO_2 values and caloric expenditure compared to the Airdyne cycle, simulated cross-country skiing, cycle ergometer, rowing ergometer, and stair stepping. Treadmill, stair stepping, simulated cross-country skiing, and rowing were all significantly ($p<0.05$) greater in caloric expenditure and VO_2 than aerobic riding and cycle ergometry. Heart rate was significantly ($p<0.05$) different among the different modalities. Treadmill, stair stepping, rowing and simulated cross-country skiing elicited significantly ($p<0.05$) higher HR than Airdyne exercise. Treadmill and stair stepping were also significantly ($p<0.05$) higher in HR compared to cycle ergometry (Zeni et al., 1996).

Pannier, Vrijens, & Van Cauter (1980) state that treadmill exercise produces a greater VO_2max than cycle ergometry. This difference generally varies between five and

10 percent and is not influenced by age or training conditions. The runners complained of localized quadriceps muscle pain during cycle testing, which might have been a limiting factor in VO_2max. Differences in VO_2max were stated as being a result of training with the cycle. It has been suggested that local metabolic and circulatory factors in the leg musculature might limit work performance on the cycle. It is thought that training with the cycle would eliminate this difference (Pannier et al., 1980; and Hagberg, Giese, & Schneider, 1978). This research compared physiologic performance in treadmill exercise and cycle ergometry, comparing trained runners and a control group (Pannier et al., 1980).

Subjects were tested in two exercise sessions. Exercise tests were maximal, however the sub-maximal data were also collected and analyzed. One test was conducted with both the cycle and treadmill to VO_2max (Pannier et al., 1980). Cycle protocol began with a warm-up at 140 watts and increased mechanical workload by 40 watts every three minutes. Pedal rate was maintained between 60-70 RPM. Treadmill incline began at a zero percent grade. After the warm-up, treadmill grade increased by 2.5 percent every three minutes. Horizontal ground speed was maintained constant, but was different for the control group versus the trained runners. Trained runners exercised at 7.75 MPH (207.7 $m \bullet min^{-1}$) and the control group exercised at 6.2 MPH (166.16 $m \bullet min^{-1}$).

Analysis of the sub-maximal exercise data observed no difference in HR in the control group between the two exercise modalities. Trained runners displayed a slightly lower HR than the control group at all levels of sub-maximal VO_2 in both exercise modalities. Pannier et al. (1980) reported numeric differences in the control group, however no statistical significance was observed in sub-maximal exercise data (Pannier et al., 1980).

Contrary to the results in the control subjects, significant ($p<0.05$) differences were observed between treadmill and cycle exercise in the trained runners when comparing treadmill and cycle ergometry in VO_2max and maximum achieved HR. Both HR and VO_2 observed significant ($p<0.05$) differences in the trained runners. Treadmill values were significantly ($p<0.05$) greater compared to cycle ergometry (Pannier et al. 1980; and Hagberg et al., 1978).

Simultaneous exercise requiring the combination of arms and legs have produced mixed results. Toner, Glickman, & McArdle (1990) reported this combined exercise distributed between the upper and lower body resulted in greater VO_2max values in comparison to cycle ergometry. This only occurs when less than 30% of the total workload is performed by the arms (Toner et al., 1990). As previously mentioned, Kravitz et al. (1997) stated this amount of exercising body mass is necessary for eliciting the increased VO_2max when assessing the combined exercise of the upper and lower body. When upper body exercise is added to lower body exercise an increase in the sympathetic neurological response occurs. The result is an increase in circulating catecholamines and a change in the distribution of blood flow. If the upper body is responsible for greater than 30 percent of the total workload VO_2max may be compromised. This phenomenon might be due to the amount of exercising muscle mass. Larger amounts of exercising muscle mass creates difficulty for the cardiorespiratory system to maximally perfuse the muscle mass, thereby causing a reduction in peak muscle blood flow to the exercising muscles during simultaneous upper and lower body exercise (Kravitz et al., 1997; and Rowell, 1988).

Wiswell & deVries (1979) also compared cycle ergometry and treadmill exercise in regards to elicited VO_2max and HR. No significant ($p<0.05$) differences were observed in VO_2max between treadmill and cycle ergometry. Mean HR peak was 194.2 with the cycle and 191.3 with the treadmill. However, the percentage of maximal HR when peaking occurred was significantly ($p<0.05$) lower in the cycle than the treadmill (Wiswell et al., 1979).

Oxygen pulse (O_2-pulse)

Oxygen pulse (O_2-pulse) is the volume of oxygen consumed by the body per heart beat (Dirckx, J. H., 1997). This is calculated by:

$$\frac{\text{Relative } VO_2}{\text{Heart Rate}} = O_2\text{-pulse}$$

As early as 1914, investigators considered maximum O_2-pulse as an important measure of cardiovascular function. Oxygen-pulse depends on stroke volume and hemoglobin in the blood, and at higher HR, O_2-pulse will plateau or will be slightly reduced. It has been suggested that maximal O_2-pulse may provide as much information about cardiorespiratory performance as VO_2max but at lower heart rates and lesser mechanical workloads. This hypothesis was made upon the observation that O_2-pulse reached its peak and reached a plateau before VO_2max or maximal HR (Wiswell et al., 1979).

Wiswell et al. (1979) compared cycle ergometry and treadmill exercise in regards to the elicited O_2-pulse time course as well as VO_2max and HR. A total of 60% of the subjects (18 of 30) reached a sub-maximal peak in O_2-pulse on the treadmill while only 43% of the subjects (13 of 30) peaked in cycle ergometry. The average HR when the O_2-pulse plateau was reached was 187.3 with the treadmill and 187.2 with the cycle ergometer. Mean HR peak was 194.2 with the cycle and 191.3 with the treadmill. However, the percentage of maximal HR when peaking occurred was significantly ($p<0.05$) lower in the bicycle than the treadmill (Wiswell et al., 1979).

Wiswell et al. (1979) provided an explanation for their observations that individuals demonstrating low HR at low work intensities, high maximal HR, and disproportionate increases in respiration for a given minute ventilation were most likely to exhibit a peak in O_2-pulse during sub-maximal exercise, regardless of the modality. They suggest factors such as hyporeactivity to metabolic acidosis and an inability of the central nervous system or respiratory control centers to stimulate ventilation for a given level of anaerobisis may have an affect on the plateau in O_2-pulse. Another explanation for peaking in O_2-pulse might be related to the effect of tachycardia on stroke volume and cardiac output. A decrease in cardiac output would be associated with higher HR because of the time for ventricular filling is compromised, therefore causing a reduction in stroke volume. It was hypothesized that HR alone is not responsible for the drop in stroke volume or the drop in O_2-pulse, but that venous return and atrial pressure may also affect the plateau or reduction in O_2-pulse (Wiswell et al., 1979).

The results Pannier et al. (1980) reported significant ($p<0.05$) differences in maximum O_2-pulse between treadmill and cycle exercise in trained runners when comparing treadmill and cycle ergometry. Significant ($p<0.05$) differences were only found in the trained runners with the treadmill values being greater in comparison to cycle ergometry. There were no differences found in the control group (Pannier et al. 1980; and Hagberg et al., 1978).

Lactate, The Lactate Threshold (LT), & Steady State

McArdle et al. (1996) define the lactate threshold (LT) as the highest exercise intensity or intensity of VO_2 that is not associated with an elevation of BLC above the pre-exercise level, or BLC of less than 1 $mmol \cdot L^{-1}$ (McArdle, et al., 1996). Examined with a graded exercise test, determination of the LT is an indirect measurement of steady state exercise, (Oyono-Enguelle, Marbach, & Heitz, 1990; and Stegmann, Kinderman & Schnable, 1981). It should also be understood that lactate does not accumulate in the blood at all intensity levels of exercise. Blood lactate accumulates and begins to rises in an exponential fashion at approximately 55-60% VO_2max in individuals who are healthy and untrained. Many researchers have stated the LT is based on a fixed BLC level of 4.0 $mmol \cdot L^{-1}$. When lactate begins to accumulate in the blood, it can be assumed that lactate production is occurring at a greater level than the rate it is removed and oxidized. Furthermore, 4.0 $mmol \cdot L^{-1}$ represents the point at when lactate accumulates in the blood lactate and thus, the body is not in steady state. The result is an acidic environment because lactate production is exceeded by lactate removal and oxidation. Therefore, the body's production of ATP has to rely on the assistance of anaerobic glycolysis to assist in the provision of additional ATP, because the energy demand of the exercise intensity is greater than the production of ATP through aerobic pathways (Beneke et al., 2000; Carter, Jones & Doust, 1999; McArdle et al., 1996; Kindermann, Simon, & Keul, 1979; Sjodin, Jacobs, & Karlsson, 1979; and Mader, Leisen & Heck, 1976).

If the oxygen supply to the muscle is reduced, the production of lactate will increase. During intense exercise in which frequent, forceful muscular contractions constrict blood vessels, the result is occluded blood flow; thus, causing increased glycolysis and ischemic hypoxia. Both of these conditions cause an increase in lactate production (Robergs et al. 1997; Stainsby, & Brooks, 1990; and Taylor, 1989).

Difficulties in determining the LT are caused by a variety of interferences due to methods of assessment and other extraneous factors. First, BLC may increase in an exponential fashion rather than in a threshold manner. Second, BLC may be different when samples are obtained from an artery, capillary, or vein. Third, BLC and the LT can be altered due to dietary change of carbohydrate intake. Fourth, BLC results from the appearance and disappearance of lactate from the blood (Robergs et al. 1997; Hughson, Cochrane, & Butler, 1993; Beaver, Wasserman, & Whipp, 1985; Yeh, Garfner & Adams, 1983; Whipp, & Wasserman, 1972). Researchers have not reached a consensus for which method of BLC assessment provides the greatest diagnostic accuracy. It is accepted that all measurement techniques have inherent problems (Carter et al., 1998).

The use of the LT for intensity regulation is based on the premise that it serves as a physiologic marker of exercise intensity. The LT provides information about relative VO_2 and provides the most complete picture of the physiological stress and metabolic demand occurring during exercise (Gladden, 2000; Yoshida, 1997; Welman, 1995; Henrizte, Welman, Schurrer, & Barlow, 1985; and Yoshida, 1984).

The LT indicates an individual's exercise intensity when the rate of lactate production exceeds the rate of lactate clearance (Beneke et al., 2000; Carter et al., 1999; Beneke & VonDuvillard, 1996; Beneke, R., 1995; Urhausten, Coen, Weiler, & Kinderman, 1993). In addition, the LT directly indicates the upper border of exercise intensity resulting in steady state of BLC. Determination of the LT is supposed to be an indirect measure of the highest exercise intensity that does not cause lactate to accumulate in the blood, as evaluated during an incremental graded exercise test (Carter et al., 1999; Urhausten, et al., 1993; Oyono-Enguelle et al., 1990; Mader et al., 1986; Heck, Mader, Hess, Mucke, Muller, & Hollman, 1985; Stegmann et al., 1981; Mader et al., 1976). However, the LT and corresponding exercise workload associated with the LT are not always correlated with a specific level of exercise performance. Thus, Beneke et al. (2000) is supported by previously published research that stated higher exercise performances reduce BLC at the LT (Beneke et al. 2000; Carter et al., 1999; Mongnoni, Sirtori, Lorenzelli, & Cerretelli, 1990; Oyono-Enguelle, et al., 1990; Allen, Seals, Hurley, Ehsani, & Hagberg, 1985; Heck et al., 1985; and Stegmann et al., 1981).

Miles et al. (1980) monitored BLC response from exercise in cycle ergometry and treadmill exercise. Using capillary finger-stick samples, BLC was measured at the end of each five-minute exercise stage. Blood lactate concentration was significantly ($p<0.05$) higher during sub-maximal cycle ergometry compared to sub-maximal treadmill exercise. Additionally, the significantly ($p<0.05$) higher BLC may reflect the use of a smaller muscle mass for a given level of metabolism for cycle ergometry in comparison to treadmill exercise (Miles et al., 1980; Faulkner et al., 1971; and Hermansen, Ekblom, & Saltin, 1970).

Based on the principle of the LT, Beneke et al. (2000) states the LT is unique due to individual differences in fitness and cardiorespiratory training that exists among subjects. Consequently, the numeric BLC value of 4.0 mmol•L^{-1} may not be applicable of all subjects (Beneke et al. 2000; Carter et al., 1999; Kiens, 1997; Phillips, Green, Tarnapolsky, Heigenhauser, Hill, & Grant, 1996; Tegtbur, Busse, & Braumann, 1992; Oyono-Enguelle et al., 1990; and Jansson, & Kaijser, 1987). Compared to VO_2max, the LT may be found at different points due to the unique physiologic requirements each exercise modality requires. The corresponding LT with VO_2 values vary significantly ($p<0.05$) when assessing BLC from the same individual exercising on a treadmill, cycle ergometer, and arm-crank ergometer. This described variance is attributed to the amount of muscle mass needed to execute the exercise (Kravits, et al., 1997; and Miles et al., 1980). Exercising a smaller mass of muscle will result in the accumulation of blood lactate at a lower corresponding VO_2. Conversely, exercising a greater amount of muscle mass will result in the accumulation of blood lactate at a greater corresponding VO_2. In respect to this phenomenon, different exercise modalities should not be used interchangeably in determining and quantifying the LT (Kravits, et al., 1997; McArdle et al., 1996; and Miles et al., 1980).

Even though exercise VO_2 was equivalent on both treadmill and cycle ergometer, a significantly ($p<0.05$) higher BLC was associated with cycle ergometry. Miles et al. (1980) suggested the observed increase in BLC occurring in cycle ergometry, was a result of the smaller muscle mass employed in cycle ergometry to produce the equivalent VO_2 workload in treadmill exercise. The smaller working muscle mass in cycle ergometry caused anaerobisis earlier compared to treadmill exercise. This response is similar to that which has been observed when arm-crank ergometry alone is compared to cycle ergometry alone. The smaller exercised muscle mass causes a greater BLC in the arm-crank ergometry in comparison to cycle ergometry. Consequently, this result also occurs when comparing treadmill exercise to the cycle ergometer. Higher BLC occurred during both maximal and sub-maximal cycle ergometry, supports the possibility of localized fatigue from anaerobic metabolism. The increased BLC was also cited as a limitation to aerobic power potential during the cycle ergometry, in comparison to treadmill exercise Furthermore, the increased BLC particularly attenuated muscular motivation due to localized fatigue and associated pain at higher intensities of exercise compared to treadmill exercise (Miles et al. 1980; Koyal, Whipp, Huntsman, Bray, & Wasserman, 1976; and Hermansen, 1973). Even at equivalent levels of metabolism, a greater disturbance of the acid-base balance occurred during cycle ergometry when compared to treadmill exercise (Miles et al., 1980).

Steady state is the point when an exercise intensity is attained, and the total ATP demand from muscle contraction is met through oxidative phosphorylation. Therefore, during steady state exercise, ATP formation with oxygen has stabilized and metabolic acidosis does not develop. Steady state refers to an achieved exercise intensity that does not observe an accumulation of lactate (Robergs et al., 1997). Maximal Lactate Steady State (MLSS) occurs when a subject is exercising at the highest external power at which a balance exists between the appearance of lactate in the blood and the rate at which the removal of lactate occurs from the blood during constant-load exercise (Beneke et al, 2000; Carter et al., 1999; Jones, & Doust, 1998; and Beneke, 1995). Lactate turnover refers to a balance in the production of and the removal of lactate during rest and exercise of moderate intensity (Brooks et al., 2000; Beneke, et al., 2000; Carter et al., 1999; Jones et al., 1998; Beneke et al., 1996; Snyder, A. C, Woulfe, T, Welsh, & Foster, 1994). However, if BLC remains at a resting level during any intensity of exercise, it would be erroneous to conclude that no lactate is being produced. During moderate-intensity exercise, when the BLC remains constant, it can be concluded that the production of lactate and the removal rate of lactate are either equal or that the removal and oxidation of lactate exceeds the production of lactate (Brooks et al., 2000; Robergs et al., 1997; and McArdle et al., 1996).

For low to moderate exercise intensities, small increases in intensity result in an exponential increase in VO_2 until steady state is reached. The ability and rapidity of attaining steady state varies depending on the magnitude of the increment of increased exercise intensity, and the fitness level of the individual. The larger the increase in exercise intensity, the longer the time interval is needed to achieve steady state. Persons with high levels of cardiorespiratory fitness will require a shorter time to achieve steady state than persons who are of a low level of cardiorespiratory fitness (Robergs et al., 1997).

Theoretically, once steady state is attained, exercise could continue indefinitely, if the individual had the willpower to continue. This theoretical situation does not take into account hydration, electrolyte balance, blood glucose and glycogen stores. Exercise performance at steady state depends largely on how well central circulation can deliver oxygen to the working muscles and how well active tissue can utilize the oxygen delivered to it (McArdle et al., 1996).

VO_2-Drift

Exercise at a sub-maximal intensity results in steady state of VO_2 at approximately three minutes after the mechanical workload has been established. Prolonged steady state exercise causes a slight increase in VO_2 known as oxygen drift (VO_2-drift). Oxygen-drift was significantly ($p<0.05$) greater during 30 minutes of downhill running at 40% VO_2max compared with level running at the same percentage of VO_2max (Westerlind, Byrnes, & Mazzeo, 1992). However, when VO_2 is evaluated for longer periods of time at steady state exercise intensities of greater than 60% VO_2max, an upward drift in VO_2 was reported (Hagberg, Mullin, & Nagle, 1978). It is speculated that a combination of increased muscle temperature and circulating catecholamines hormones contribute to the VO_2-drift during level running. An increase in body temperature directly effects the neurons in the respiratory center which increases ventilation in long-duration exercise (McArdle et al., 1996). A greater catecholamine release indicates a greater capacity for stress hormone synthesis after training (Robergs et al., 1997). Apparently, the larger VO_2-drift associated with downhill running is not caused by muscle damage, but is a result of greater increases in muscle temperature caused by eccentric muscular contractions (Robergs et al., 1997; and Westerlind et al., 1992).

Research by Beneke et al. (2000) analyzed a possible relationship between performance capacity expressed as VO_2max reached at the end of an incremental load test and steady state, the associative steady state workload in watts, and steady state intensity of VO_2 measured during constant workload. Thirty-three male subjects of similar age and weight were studied, however their backgrounds and level of training varied. Subjects performed the incremental, constant-load cycling protocol for a total of six to 12 total tests over the course of the study. The greatest exercise intensity at which BLC increased by no more than 1.0 mmol•min^{-1} during the final 20 minutes of the tests was determined to be the greatest exercise intensity at which steady state could be attained. This point was also referred to as the LT for this research. Blood lactate concentrations were measured at 15, 20, 25, and 30 minutes of the highest steady state exercise workload. Capillary blood samples were taken from the subject's earlobe before each test and at the specific increment during each test (Beneke et al., 2000).

The results of Beneke et al. (2000) confirm previous research that state many variables exist that affect blood lactate accumulation. A steady state workload of VO_2 and the highest level of VO_2 steady state were not correlated among subjects with exercise performance. At given exercise workloads, high performance athletes have lower BLC levels than subjects of low fitness. Furthermore, fitness and endurance training, adaptations of heart, blood, muscles, and hormones change the production, distribution and elimination of pyruvate and consequently change BLC levels at given VO_2 workloads among different subjects (Beneke et al., 2000).

Muscle glycogen is reported to decrease less rapidly in endurance-trained athletes than in untrained subjects. Thus, at a given workload, increased endurance performance reduces the glycolytic rate, which increases the rate of fat oxidation, and results in a lower BLC level. Furthermore, the duration of aerobic exercise up to LT exercise intensity is limited by stored energy. Also, muscular creatine phosphate concentration is reduced and the pH of both the muscle and blood decrease. In combination, these factors cause the eventual termination of exercise (Beneke et al. 2000; Beneke, R., 1995;

Urhausten, et al., 1993; Mader, et al., 1986; Allen, et al., 1985; and Heck, et al., 1985). Consequently, the LT does not indicate a specific workload but, rather, an intensity of exercise that is specific to the individual's physiologic responses, which are based on variance due to differences in individual fitness levels (Beneke et al. 2000; and Carter et al., 1999). Thus, at a given workload, increased endurance exercise performance will reduce the glycolytic rate, increase the rate of fat oxidation, and will also lead to lower BLC levels (Beneke et al. 2000; Kiens, 1997; Phillips et al., 1996; Coggan, Spina, Kohrt, & Holloszy, 1993; Turcotte, Richter & Kiens, 1992; and Jansson et al. 1987).

Lactate and Rating of Perceived Exertion (RPE)

Subjects' personal ratings of perceived exertion is the single best indicator in determining the degree of physical strain subjects are experiencing during exercise. The overall rating of perceived exertion integrates information from the cardiorespiratory system, peripheral working muscles and joints, and the central nervous system. It is the summation of all these variables that quantify and qualify an individual's perception of exertion (Borg, 1982).

Borg (1970) introduced the Borg's Scale of Rating of Perceived Exertion (RPE) in 1970 (Borg, 1970). This scale was designed to be implemented with graded exercise tests conducted on the cycle ergometer and is designed to increase linearly with heart rate, VO_2, and mechanical workload. Early Pearson r Correlations indicated strong relationships in both subject psychological self-perception of effort and collected physiological variables of RPE and heart rate, observing a range of 0.80-.090 (Borg, 1982; Mihevic, 1981; and Borg, 1970). The Borg's Scale of RPE ranges numerically from 6 to 20 and is designed to be loosely applied to heart rates ranging from 60-200 beats per minute. Since it is well documented that maximum heart rate decreases with an increase in age, the Borg's scale of RPE is best applied with subjects that range in age from 20-50 years old. However, the close relationship of the Borg's Scale of RPE and heart rate should not be taken too literally because the meaning of a certain heart rate value as an indicator of stress depends on a subject's age, type of exercise, exercise environment, and the anxiety of the subject (Borg, 1982).

Research has observed a strong correlation between RPE and the LT when testing moderately conditioned young men and women. Even independent of exercise type, training state and/or training specificity, BLC is well correlated with RPE during exercise (Moreau, Whaley, Ross & Kaninsky, 1999; Stoudemire, Weidman, Pass, McGinnes, Gaesser, & Weltman, 1996; Welman, 1995; Edwards, Melcher, Hesser, & Wigertz, & Eklund, 1972). Furthermore, RPE has been used as a surrogate marker for exercise prescription intensity when the LT is the preferred intensity criterion (Moreau et al., 1999; Stoudermire et al., 1996; Steed, Gaesser, & Weltman, 1994; Haskivts, Seip, Welman, & Rogol, 1992; Hetzler, Seip, Boucher, Pierce, Snead, & Welman, 1991; Boutcher, Seip, Hetzler, Pierce, Snead, & Welman, 1989; and Demello, Cureton, Boineau, & Singh, 1987). All these factors are supporting RPE to possibly be an effective tool in determining exercise intensity for subjects (Stoudermire et al., 1996; Demello et al., 1987; Seip et al., 1991; Foxdall, Sjodin, & Sjodin, 1996; Hetzler et al., 1991; and Ekblom, & Goldbarg, 1971).

Despite the amount of scientific support for RPE being an indicator of exercise intensity related to BLC, some research concluded little or no direct relationship between RPE and BLC during various modalities of exercise. There appears to be considerable inter-individual variability in the RPE:BLC relationship. Consequently, many researchers state that if RPE is to be used to define exercise intensity in exercise prescription, it must be defined first by specific physiological markers of BLC, VO_2 and the percentage of VO_2max at which the LT is associated. This is stated to establish the actual physiologic level of exercise intensity (Moreau et al., 1999; Thompson, & West, 1998; Weltman, Kanaley, Rogol, Hartman, Veldhuis, & Weltman, 1997; Whaley, Woodall, Kiminsky, & Emmett, 1997; Glass, Knowlton, & Becque, 1991; Potteiger, & Evans, 1994; Ceci, & Hassmen, 1991; Loggen, Graham, & Sjogaard, 1980; and Stamford, & Nobel, 1974).

The over-all perception of effort is suggested to represent multiple physiological sensory inputs of "central" changes in the cardiorespiratory system integrated with "local" feelings of strain in the exercising muscles and joints. Various researchers agree that a combination of stimuli influence RPE. Oxygen demand is considered a primary central determinant of RPE, therefore exercises such as cycling, and treadmill walking and running, should be different in the subject's interpretation of their exercise effort. Differences in RPE are suggested to be related to: 1) subject age, 2) gender, 3) habitual activity, 4) physical training, 5) body weight, and 6) the modality of exercise. Other factors are greatly reduced or eliminated when evaluated at a given percentage of each individual's VO_2max. In addition, various researchers have stated the relationship of RPE and VO_2 may be spurious and may reflect the perception of other more fundamental responses. It should be noted that relative aerobic demand represents only a part of the central signal for the sensation of effort. The sensation of discomfort that is associated with respiratory function provides an additional signal at higher exercise intensities. An important finding was that RPE is not affected by the level of physical fitness in both trained and untrained subjects, when exercising at the LT. Trained distance runners and untrained subjects perceive exercise intensity at the LT as a rating of "13" or "somewhat hard". This data is consistent with other studies that have reported mean RPE values, when exercising at the LT, to fall between "12" to "14" on the Borg's Scale of RPE. These results include a variety of populations. A strong correlation has also been reported in the association of RPE and the LT in highly trained males and master's division distance runners (Demello et al., 1987; Allen et al., 1985; Carton & Rhodes, 1985; Hellerstein, & Franklin, 1984; Bellew, Burke, & Jensen, 1983; Robertson, 1982; and Mihevic, 1981).

Zeni et al. (1996) observed that BLC appeared to be an important mediator the affected RPE during aerobic exercise. At the end of each five-minute exercise stage, a capillary blood sample was immediately extracted from a fingertip and was analyzed for BLC. During self-selected exercise intensities using the Borg's scale of RPE, similarities between BLC and RPE existed among all exercise machines, except for the simulated cross-country skiing machine. Results indicated increases in BLC with increases RPE, however this relationship varied significantly ($p<0.004$) among exercise machines. Zeni et al. (1996) observed that exercising a larger muscle mass created a greater demand for oxygen and increased heart rate, at a given RPE. If the amount of muscle mass was the only criteria for various metabolic demands, it would be expected simulated cross-country skiing and rowing would engage a larger muscle mass and thus, elicit a greater VO_2 and caloric expenditure than treadmill walking or running. It is also hypothesized that there is no one variable that influences RPE (Kravitz et al., 1997; and Zeni et al., 1996). This is might also be an indication that BLC is not the sole mediator of RPE among modes of aerobic exercise. Previous research has thoroughly documented that RPE increases when there is an increase in BLC (Zeni et al., 1996; Hetzler et al, 1991; Boutcher et al., 1989; Demello et al., 1987; Haskivts et al., 1992).

Demello et al. (1987) reported both men and women, along with trained and untrained subjects, demonstrated close associations of RPE and LT. This occurred even though LT occurred at substantially different percentages of VO_2max in individual subjects. This was credited to the individual levels of training and fitness. Thus, the LT is an important physiological point for perception of effort during exercise (Demello et al., 1987).

Metabolic and gas exchange alterations are initiated by the LT and become accentuated at higher intensities that could contribute both local and central signals of perception of effort. At exercise intensities above the LT, lactate accumulates in the active muscles and blood, causing an increase in ventilation, resulting in a disproportionate rate of ventilation in relation to the work rate and VO_2 (Jones, & Ehrsam, 1984).

Pandolf, Kamon, & Noble (1978), reported muscular tension is greater during the concentric muscular contraction of the muscular movement in comparison to the eccentric phase. Likewise, RPE is higher when performing concentric work compared to RPE with eccentric muscular contractions (Kolkhorst, Mittelstadt, & Dolgener, 1996; and

Pandolf et al., 1978). If the amount of tension development by muscle also serves as a primary sensory input for RPE, it may be possible to assume that concentric muscular work should require greater effort than eccentric muscular work (Kolkhorst et al., 1996; and Cafafelli, 1982). Nardone, Romano, & Schieppati, (1989) and Nardone, & Schieppati, (1988) state there is a shift in motor unit recruitment patterns during concentric and eccentric muscle movements. A significant ($p<0.05$) increase is reported in the recruitment of fast-glycolytic motor units with a concurrent decruitment of slow-oxidative units during eccentric movements. This suggests that downhill running, in comparison to uphill running, causes greater recruitment of fast-glycolytic fibers and less slow-oxidative fiber recruitment. Since fast-glycolytic fibers have a lower oxidative capacity and, therefore, produce more lactate than slow-oxidative fibers, the physiologic differences between the fast and slow fibers is speculated to be assessed by various sensory receptors, which also might influence RPE. This may explain the difference in RPE between different muscle fiber types, specifically when assessing eccentric and concentric work (Kolkhorst, et al., 1996; Nardone et al., 1989, and Nardone et al., 1988).

Ceci et al. (1991) evaluated the physiological response to treadmill and outdoor track exercise during self-selected exercise intensities chosen by the subjects. The self-selected exercise intensity was thought to more accurately emulate a personal pace of exercise during a typical exercise bout (Ceci et al., 1991). In addition, Van Den Burg, & Ceci, (1986) implemented specific RPE ratings in order to produce a certain physiologic exercise intensity during level treadmill running. This study found no differences in speed or heart rate between a production protocol and an estimation protocol. However, Van Den Burg e al. (1986) found significant ($p<0.05$) differences when crosscomparisons were made with the lab test on the treadmill and the field test of outdoor track running. Eston, Davies, & Williams (1987) discovered a Borg's Scale of RPE range of "11" to "15" corresponded to a range of about 60-80% VO_2max. Eston et al. (1987) summarized their study by stating that it would be of interest to further study whether the magnitudes of the measured variables or heart rate, BLC and velocity, obtained from the treadmill running are comparable to those values obtained from outdoor field running (Ceci et al., 1991; Eston et al., 1987; and Van Den Burg e al., 1986).

Physiologic Response Elicited from the Elliptical Exercise Modality

Description of the Miller Walker Transport

The Miller Walker Transport is one of the earliest prototypes of elliptical exercise machines and has been the foundational apparatus for the research of Bates & Mercer (1994), Bates (1995), and Mercer, Dufek & Bates (2001). Observations have shown the elliptical exercise modality of exercise to be an excellent choice for gaining cross-training benefits because of its versatility. The elliptical exercise has a similar motion that feels like a combination of treadmill, cycle ergometry, and stair stepping exercises. They reported the biomechanics of the elliptical exercise are touted as being an excellent thigh exercise and is a motion similar to both treadmill and stair stepping machines. However, the elliptical exercise machine is reported to feel more like moving up real steps when compared to stair stepping exercise machines. Exercising people can also modify the pattern of the elliptical-shaped motion to further change the exercise intensity, effort, and muscular focus of the exercise session, and thus, modify the physiologic and metabolic demand to complete the movement. Adjustments in mechanical exercise intensity and changes in biomechanics can be made by either changing the ramp incline or changing the steps per minute. Subjects can also adjust the flywheel resistance (Bates, 1995; Bates et al., 1994).

Biomechanics of the Miller Walker Transport

Bates et al. (1994) provides a more in-depth description of the beneficial biomechanics of exercising on the Miller Walker Transport including an excellent range of motion. In the knee joint, range of motion is greater in the elliptical exercise modality in comparison to treadmill exercise. However, the elliptical apparatus accounted for slightly less range of motion at the knee joint when compared with the stair stepping exercise. Furthermore, the elliptical exercise apparatus forces a range of motion, which causes a deliberate, consistent stepping motion, distance, and range of motion. The elliptical apparatus forces body to exercise symmetrically due to the right-left dependence. It also creates excellent hip extension and flexion, which enhances hip range of motion compared to stair stepping and treadmill walking and running. Finally, the elliptical exercise modality is a fluid, symmetrical, non-impact form of exercise (Bates, 1995; Bates et al., 1994).

Due to impact on joints of the body caused by some modalities of exercise, Kravitz et al. (1997) stated that numerous injuries have occurred due to the eccentric loading at contact. The advantage of the elliptical exercise is that the impact between the foot and the ground is eliminated, which is hypothesized to be related to overuse injury during running (Mercer et al., 2001; and Bates et al., 1994). In addition, the mechanics of elliptical exercise is related more to treadmill and stair stepping exercises than cycle ergometry because the subject is supporting bodyweight by standing on the apparatus, unlike cycle ergometry, which supports the subject's bodyweight (Bates et al., 1994).

Electromyographical Analysis of the Miller Walker Transport

Electromyographical (EMG) data and joint position was collected and curves developed from 10 subjects performing exercise on the Miller Walker Transport in both lowest, middle, and highest ramp settings. Comparisons were made with exercise on a treadmill at a zero and 15% incline, and a stepping machine. The movement frequency was maintained across all three conditions in order to compare the results across all conditions (Bates et al., 1994).

The results of Bates et al. (1994) found the Miller Walker Transport to be significantly ($p<0.05$) greater in stimulating gluteus maximus, vastus lateralis, vastus medialis, and rectus femoris muscles in both highest and lowest ramp settings. However, the treadmill resulted in significantly ($p<0.05$) greater stimulation of the biceps femoris and calf stimulation. Analysis of EMG comparing stair stepping ergometry to the Miller Walker Transport resulted in the elliptical exercise being significantly ($p<0.05$) greater at stimulating gluteus maximus and biceps femoris. Stair stepping ergometry stimulated the calves significantly ($p<0.05$) greater than elliptical exercise. Similarities in EMG were observed in vastus lateralis, vastus medialis, and rectus femoris when comparing exercise with the Miller Walker Transport and stair stepping (Bates et al., 1994).

Cardiorespiratory Responses with the Miller Walker Transport

Mercer et al. (2001) evaluated elliptical exercise compared to treadmill exercise in a test of VO_2max. All subjects participated in two maximal effort graded exercise tests, one test for each respective exercise modality. The design of both tests was to elicit VO_2max in a range of time from eight to 15 minutes total exercise time. Stage times were one minute in duration. In the treadmill exercise, an eight percent grade was set and did not change at any point during the test, however speed was increased each minute until the subject reached VO_2max. In the elliptical exercise test, the ramp setting was at the midpoint of the total ramp incline range and did not change at any point in the test. Step cadence began at 60 RPM and was increased by five steps per minute each one-minute stage until VO_2max. In addition, there were some subjects that could not maintain the proper step cadence. If that occurred, the individual was given 15 seconds to regain the proper stepping cadence. If they were unable to regain cadence, the test was terminated (Mercer et al., 2001).

The results of Mercer et al. (2001) observed no statistical difference between elliptical and treadmill exercise. The HR to VO_2 correlations during elliptical exercise ($r=0.88$) and treadmill exercise ($r=0.95$) showed close similarities between modalities. Mercer et al. (2001) observed no differences between machines for any of the peak HR, VO_2max, and peak RPE for this research indicating that during treadmill and elliptical exercises, HR and VO_2 increased in similar fashion for different levels of mechanical exercise intensity. These results indicate elliptical exercise provides a range of mechanical and physiologic exercise intensity that is similar to treadmill running (Mercer et al., 2001).

Spranger (1998) compared the physiological responses elicited by five different exercise modalities, one of which was an elliptical exercise trainer. Ten apparently healthy, female subjects, ages ranging from 20-26 were used in this research. Spranger (1998) tested each subject on five exercise modalities: 1) air walker, 2) elliptical trainer, 3) simulated cross-country skiing, 4) treadmill walking, and 5) Airdyne cycling. Heart rate, VO_2, and RPE were recorded, while O_2-pulse was calculated using VO_2 and heart rate data after they were collected. For each individual exercise session, subjects completed a five-minute warm-up, then exercised for a 30-minute session. Subjects were instructed to exercise at a self-selected pace similar to if they were in a recreational exercising setting (Spranger, 1998).

Spranger (1998) observed VO_2 and caloric expenditure to be significantly ($p<0.05$) higher on the elliptical exercise compared to simulated cross-country skiing and airdyne cycling modalities. Heart rate was significantly ($p<0.05$) lower in the simulated cross-country skiing compared to elliptical exercise. Perceived exertion ratings for elliptical exercise were significantly ($p<0.05$) higher in comparison to treadmill walking. No differences ($p<0.05$) were observed in O_2-pulse when comparing the elliptical exercise and treadmill walking. However, the O_2-pulse measurements for both elliptical exercise and treadmill walking were significantly higher ($p<0.05$) than the air walker, simulated cross-country skiing and Airdyne cycling. The elliptical exercise elicited the greatest VO_2 and therefore the greatest caloric expenditure. In addition the elliptical exercise elicited the greatest exercising heart rate compared to other modalities. Spranger (1998) explained the elliptical exercise most resembled treadmill running or walking, and therefore the elliptical exercise should elicit the greatest VO_2 and heart rate. This statement about treadmill exercise is in agreement with previous research concerning treadmill research (Spranger, 1998; Kravitz et al., 1997; Zeni, et al., 1996; Thomas et al., 1995; and Thomas et al., 1989). Finally, Spranger (1998) stated one strength of this study was the fact that self-selected exercise intensities were implemented, rather than a specific exercise intensity based on pre-established criteria. This methodology is implemented because of it is thought to be a better reflection of how people will actually use the each apparatus when exercising recreationally (Spranger, 1998).

Bates & Mercer (1997) assessed the metabolic cost of the elliptical exercise modality at three different mechanical exercise intensities. The three exercise conditions involved changes in step cadence, changes in flywheel resistance, and changes in ramp incline. In these three exercise conditions, two of the variables were remained fixed throughout the test and the other variable was manipulated. In condition one, ramp incline was constant at the midpoint value of "5" and the stepping cadence remained constant at 65 RPM, however, resistance was varied (1,2,3,5), with a setting of "10" being the maximum resistance. In condition two, stepping cadence was varied (60, 70, 80, 90 RPM), ramp elevation was constant at level 5, and the resistance remained constant at level 2. In condition three, ramp elevation was increased (1, 5, 10), stepping cadence remained constant at 65 RPM, and resistance constant at level 2. In all testing conditions, the total time exercise was 10 minutes or until the subject was too fatigued to continue (Bates et al., 1997).

The results of Bates et al. (1997) observed a linear relationship in both HR and VO_2. These variables increased with the incremental increases in resistance, in condition one. In condition two, HR and VO_2 also increased linearly with the increase in stepping cadence. In condition three, changes in ramp incline did not have a significant ($p<0.05$) effect on VO_2 and HR. However, it was reported that a ramp incline set at level 5 elicited a significantly ($p<0.05$) lower VO_2 compared to levels one and 10. In addition, the results also stated that test participants subjectively rated the quadriceps as being used to a greater extent at elevation 10 while the hamstrings were used more at level one (Bates et al., 1997).

Summary of Chapter II

It has been reported in Chapter II that exercise performed on different exercise modalities can elicit different physiologic responses in subjects that are both trained and untrained in both set exercise intensities and self-selected exercise intensities (Kravitz et al., 1997; Zeni et al., 1996; Thomas et al., 1995; and Miles et al., 1980). Conversely there was research that stated no differences in physiologic responses when comparing different exercise modalities (Thomas et al., 1989; and Pannier et al., 1980). The exercise modalities discussed in Chapter II were treadmill exercise, cycle ergometry, arm-crank ergometry, simulated cross-country skiing, shuffle skiing, simulated rowing, stair stepping, and elliptical exercise. The elliptical research that has been published has been mostly experimental to measure the associated physiologic demands necessary for execution of this new exercise modality. With only one exception, the elliptical exercise tests have been relatively short duration, less than 15 minutes (Bates et al., 1997, and Bates et al., 1994), which does not follow ACSM guidelines for exercise prescription (Franklin, 2000). Also, there has been no published research to date dealing with the LT and BLC during assumed steady state exercise.

Previous research has observed and reported that HR, VO_2, O_2-pulse, and RPE are related linearly to changes in mechanical exercise workload (Kravitz et al., 1997; Zeni et al., 1996; Thomas et al., 1995; Bates et al., 1997; Bates et al., 1994; and Miles et al., 1980). Also, the LT is not a specific physiologic or mechanical workload of exercise intensity for all persons, but it is individualized based on a person's fitness level and previous training. Previous research has also demonstrated that blood lactate accumulation occurs not only due to the individualized VO_2 of the LT, but is influenced by exercise modality due to hypothesized changes in localized circulation and metabolism (Moreau et al., 1999; Thompson et al., 1998; Weltman et al., 1997; Whaley et al., 1997; Glass et al., 1994; Potteiger et al., 1994; Ceci et al., 1991; Loggen et al., 1980; and Stamford et al., 1974).

CHAPTER III

METHODS

Chapter III includes a description of the subjects, the methods implemented and the equipment used for the exercise tests. Also the design of the research and the set-up of the statistical analyses are included. Included, also, is a description of the elliptical trainer and the mechanical adjustments associated with it and a description of the analysis for BLC.

Subjects

This study included 18, college-age males, ranging in age 18 to 24 years. Subjects were students attending a large Midwestern university and were obtained on a voluntary basis through written and verbal solicitation. Each subject needed to be regularly participating in aerobic exercise, non-smoking, asymptomatic, and healthy as deemed by the Physical Activity Readiness Questionnaire (PARQ) (Appendix A). The PARQ is an instrument that allows the subject to self-report their medical history, use of medications and exercise habits. Subjects also needed to possess a minimum VO_2max of 42.22 $ml{\bullet}kg{\bullet}min^{-1}$, which ranks in the 50^{th} percentile for the age range of 18-24 years old (Franklin, 2000). Predicted VO_2max was measured in the second week of this research via a Bruce Treadmill Protocol (Appendix D). The measurement of predicted VO_2max was also used only as inclusion criteria for the remaining procedures in this research, and to ensure a homogeneous subject pool in cardiorespiratory functioning. All subjects needed to be currently participating in regular aerobic exercise at least three sessions per week for a minimum weekly accumulation of 90 continuous minutes of cardiorespiratory exercise, which was also evaluated in the PARQ. Eighteen subjects were selected from the total pool of 20 volunteers. Applicants were selected for participation based on the meeting of the established health history, current exercise habits, and fitness criteria. Two subjects were removed from the research because of personal conflicts with testing schedules.

This research was conducted in five consecutive weeks consisting of one meeting time per week, each session lasting approximately one hour. Subjects were evaluated at the same time of day for each session and subjects were not tested within 72 hours of any other test. Approval for this research was granted by the Institutional Review Board at Oklahoma State University, Stillwater, Oklahoma (Appendix G).

Description of the PRECOR EFX Elliptical Fitness Crosstrainer

Through discussions with the manufacturer of the elliptical trainer used in this research, it was assured the biomechanics of subjects and the mechanical performance of the elliptical machine did not changed from the 1994 prototype to the model being implemented in this research (Birrell, J., personal communications October, 1 2000). This research tested the PRECOR EFX546 Elliptical Fitness Crosstrainer.

Adjustment of Workload on the Miller Walker Transport

Mechanical workload on the elliptical trainer can be adjusted by changing the ramp incline, increasing or decreasing the resistance applied to the flywheel, and/or changing the rate of stepping. Incremental flywheel resistance is applied by an electromagnetic brake, which ranges arbitrarily from one to 20. A resistance setting of one is the minimal possible resistance and 20 is the greatest possible resistance setting on the elliptical trainer. The incline ramp ranges from 10 to 40 incline, and is also in 20 incremental stages with one being the lowest ramp setting and 20 being the highest ramp setting. These increments of incline are also arbitrary in their measurement. When the ramp is in the center position, the biomechanics of a person using the elliptical trainer were reported to be closely related to treadmill exercise when the treadmill incline was set at an eight percent grade (Mercer, J., personal communications February, 1 2001 & Mercer et al., 2001). The horizontal distance of each step of the elliptical trainer is identical with all other steps, regardless of the ramp or the resistance setting. Vertical stepping distance is adjusted with changes to ramp incline. In addition, the elliptical trainer forces a range of motion, causes bodily symmetry due to the right-left dependence, and is a fluid, symmetrical, non-impact form of exercise (Bates et al., 1997; Bates, 1995; and Bates et al., 1994).

Blood Lactate Analysis and the Accusport Portable Lactate Analyzer

Assessment techniques analyzing BLC from the blood sample involves the initial enzymatic conversion of lactate to pyruvate, followed by the measurement of a substance produced or consumed in the reaction. The Accusport Potable Lactate Analyzer uses reflectance photometry, which takes 60 seconds to measure the color developed by a drop of blood or plasma placed on the reagent strip. The lactate specimen is converted via lactateoxidase mediator reaction to molybdeum blue. To assess the accuracy of the Accusport Lactate Analyzer, which assesses capillary BLC, 32 blood samples at varying levels of lactate were analyzed. Comparisons were made from capillary samples collected from a fingertip, assessing BLC with both the Accusport Lactate Analyzer and the Kodak Ektachem E250. Reliability comparisons for each device were made at 1.7 mmol•L^{-1}, a low BLC, and at 14.4 mmol•L^{-1}, a high BLC (Fell, Rayfield, Gulbin, & Gaffney, 1998).

Based on the results of Fell et al. (1998), the Accusport Lactate Analyzer was in good statistical agreement with the Kodak Ektachem E250. This means that there was not enough variance or discrepancy in the analyzed BLC evaluated by either device. Differences in BLC did not exceed 1.1 mmol•L, even with very high concentrations of blood lactate. Furthermore, the Accusport Lactate Analyzer was reported to be accurate and linear up to at least 18.7 mmol•L of BLC and has good reliability at high and low concentrations of blood lactate. If the research necessitates delayed measurement of blood lactate samples, the Accusport Lactate Analyzer is able to analyze whole blood up to 15 minutes after the sample was collected and applied to the reagent strip (Fell et al., 1998).

Procedures

Week One: Initial Health Assessment, Informed Consent, Modality Familiarization, & Pretest Instructions

Subjects were familiarized with testing procedures, the different exercise protocols being used, the treadmill and elliptical modalities, and the expectations of both the research and the researcher. Subjects also were given the Physical Activity Readiness Questionnaire (PARQ). The PARQ is a written questionnaire that assessed the subject's health history, current medication use, and current exercise habits. Also in this meeting, subjects were given a preliminary health examination, which evaluated resting blood pressure and resting one-minute heart rate. These variables were measured after the subject arrived to the laboratory and was seated for five minutes. Resting blood pressure was measured manually using a mercury sphygmomanometer and stethoscope with the subject seated. As deemed by the ACSM (Franklin, 2000), healthy blood pressure is <140 mmHg, systolic, and <90 mmHg, diastolic. After the subject sat for five minutes, resting one-minute heart rate was measured with the subject seated using a Polar Heart Rate Monitor. A healthy one-minute, resting heart rate is not being tachycardic (<100 BPM). After being determined healthy by the aforementioned standards established in the PARQ, resting blood pressure, resting heart rate, and exercise habits, subjects were qualified for the testing of predicted VO_2max. Subjects were also given a description of and information concerning the proper use of the Borg's Scale of Perceived Exertion (RPE).

To ensure all subjects were comfortable with both treadmill and elliptical modalities, participants were questioned concerning the proper use of both exercise machines. Before testing began, each subject needed to feel comfortable, balanced, and proficient during exercise with both elliptical and treadmill exercises. Before testing with either modality, subjects were asked to demonstrate their ability to exercise proficiently on both exercise machines. Proficiency was determined subjectively as exercising a minimum of five minutes without a loss of balance and exercising without the aid of holding onto support bars surrounding the machine. All subjects were required to practice with both exercise modalities in recreational exercise sessions. A written 15-minute protocol was given to each subject. Treadmill practice sessions had subjects exercise at different treadmill horizontal ground speeds and grades of ramp incline. The first elliptical practice session had subjects exercise at different stepping rates, resistance settings, and different ramp inclines. During the second practice session with the elliptical modality, subjects were instructed concentrate on maintaining 155 ± 5 steps per minute with the ramp in the center position. Subjects were given specific resistance settings to follow.

In the initial stages of acclimation in each exercise modality, grasping the support handles was encouraged. When balance and comfort were achieved, subjects were encouraged not to touch the support handles during exercise. Contact with the support handles around each machine was prohibited. However, two fingers of one hand resting on the support handles were allowed for balance purposes only. Grasping the support handles was only allowed in a momentary loss of balance or when the safety of the subject was possibly in danger. Subjects who had difficulty with balance, comfort, and proficiency with either exercise modality were required additional practice sessions until a satisfactory level of exercise proficiency was gained (Moreau et al., 1999). If subjects encountered difficulty achieving balance and proficiency during any of the testing sessions, the testing procedure was terminated and the individual was required to return to the laboratory for a retesting session of that particular procedure. Examples of difficulty during exercise included 1) a loss of balance, 2) an inability to maintain step cadence with elliptical, 3) if the subject needed to grasp the handles of the exercise apparatus, or 4) failure of testing equipment. If any of these occurred during testing the exercise test was terminated and scheduled for retesting.

For each scheduled exercise session, subjects reported to the exercise testing laboratory. Subjects were instructed to be well-rested and having refrained from ingesting food, alcohol, tobacco products or caffeine for a minimum of three hours prior to testing. Subjects were instructed to wear comfortable athletic clothing and athletic shoes. Subjects were also asked to have not engaged in strenuous exercise 48 hours prior to the any of the exercise tests. However, since exercise tests occurred only one time per week, subjects were encouraged to continue their regular exercise program throughout the duration of the study.

Week Two: Determination of Predicted VO_2max

The Bruce Treadmill Protocol (Appendix D) was implemented on a motorized treadmill in order to predict the VO_2max of each subject. This test was used determine the subject's fitness level and was only used as an exclusion criteria. Subjects who were unable to successfully attain the 50th percentile VO_2max of 42.22 ml•kg•min^{-1} were excluded from further participation in this study.

Stages of this treadmill test lasted three minutes. Changes in mechanical exercise workload occurred by an increase in both the treadmill's horizontal ground speed and percent grade of uphill incline. Each stage increased incrementally in intensity by approximately 10 ml•kg•min^{-1}, or approximately three metabolic equivalents (METS).

The Bruce Treadmill Protocol was terminated when the subject first reached any one of the following: 1) 85% of maximal predicted heart rate (220-AGE), 2) if the subject experienced difficulty (unusual pain, difficulty breathing, sudden changes in blood pressure, heart arrhythmia, etc.), 3) if there was a mechanical failure of exercise or evaluation equipment used in this research, or 4) if the subject chose to self-terminate the test. Predicted VO_2max was mathematically estimated based on each subjects' age-dependent maximum predicted heart rate (220-AGE), and the associated relative VO_2 for each stage. Each stage of this sub-maximal test used metabolic calculations for walking and/or running (Appendix B) to calculate the predicted associated relative VO_2max for walking and or running (Franklin, 2000).

Heart rate of the subject was continuously monitored using a Polar Heart Rate Monitor, which used a chest strap transmitter and a wristwatch-like receiver. To ensure accuracy, three Polar receivers were be used, two were mounted on the test apparatus and the other on the wrist of the subject. Two of the three heart rate monitors needed to be in numeric agreement when collecting HR data, due to difficulty with synchronicity between the HR monitors. The 15-point Borg's Scale of RPE (Appendix C) was also utilized (Borg, 1982). Heart rate and RPE were assessed in the last five seconds of each three-minute stage (Franklin, 2000).

Upon termination of the Bruce Treadmill Protocol (Appendix D), subjects entered an active cool-down stage and walked at a slow pace (comfort choice of the subject), for three minutes or until the subject's HR stabilized. Heart rate and RPE were measured in the last five seconds of each minute during the three-minute of the active cool-down stage (Franklin, 2000). If the subjects desired, they were allowed to continue walking past the three-minute mark designated as the end of the active recovery stage. After active recovery, the subject began passive recovery with the subject seated. Heart rate was assessed in the last five seconds of each minute during the passive cool-down stage. This process continued for a total of five minutes after the active recovery stage (Franklin, 2000).

Week Three: Determination of the Lactate Threshold & Associated Prediction Variables

Before participants arrived at the laboratory, the metabolic cart was calibrated according to the manufacturer's specifications for the Quinton Q-Plex 1 metabolic cart. Resting measurements of HR and blood lactate concentration (BLC) occurred after the subject sat for five minutes after arriving at the laboratory. These measurements were used as baseline physiologic data. Subjects were fitted with the headgear and mouthpiece and were given instructions concerning the testing procedure, the treadmill protocol, the metabolic cart, blood lactate samples, and hand signals for communication during the test. Subjects were also given opportunity to ask questions concerning the test procedure.

To determine the LT, the treadmill was set at a zero percent grade of incline and did not change throughout the test. Each subject began the test with a warm-up stage by walking on a level treadmill at 3.4 to 3.7 miles per hour (91.12 to 99.19 $m \cdot min^{-1}$) for three minutes. Horizontal ground speed was the choice of the subject but needed to be within the aforementioned parameters. This warm-up period was used not only as a metabolic warm-up but also as an acclimation period for the subject due to the possibility of altered balance from using the headgear and mouthpiece. Treadmill ground speed began at 4.0 MPH (107.2 $m \bullet min^{-1}$). Every three minutes, horizontal ground speed increased by 0.4 MPH (10.72 $m \bullet min^{-1}$) and was repeated until the LT was detected (Carter et al., 1999).

Two criteria were used to state when the LT was reached. First, the LT was numerically set at 4.0 $mmol \cdot L^{-1}$ (Carter et al., 1999). However, to account for the possibility the LT was not exactly 4.0 $mmol \cdot L^{-1}$, subjects exercised for one additional three-minute stage beyond the point at which 4.0 $mmol \cdot L^{-1}$ BLC was first discovered. Second, subjects needed to display a marked increase in BLC equal to or greater than 1.0 $mmol \cdot L^{-1}$ greater than the previous measurement. These criteria displayed that blood lactate was increasing exponentially and was being produced at a greater rate than lactate was being removed. This point of BLC was referred to as the LT for each subject (Carter et al., 1999). There were no subjects in this research that had a LT different than the stated parameters.

With the subject exercising, BLC was evaluated from a blood sample extracted from a fingertip capillary. Blood samples were extracted after cleaning the fingertip with an alcohol swab. After allowing the cleaned area to dry, the fingertip was punctured with an automated lancet. The blood sample was transported from the finger by disposable transfer pipette (Carter et al., 1999). The blood sample was placed onto the lactate strip and immediately analyzed for BLC by the Accusport Portable Lactate Analyzer. This analysis took 60 seconds to complete.

Variables collected during this treadmill test were: 1) HR, 2) relative VO_2, 3) BLC, and 4) RPE. Relative VO_2 was measured every 30 seconds by the Q-Plex 1 metabolic cart. Measurement of BLC was measured in the final 30 seconds of each three-minute stage, however BLC values were recorded when the 60 second analysis was completed. Heart rate, VO_2, and RPE were recorded in the final 5 seconds of each stage (Stoudemire et al., 1996; and Weltman et al., 1996). Hand signals were used to indicate how the subject was tolerating the stress of the exercise test. A hand signal of a "thumb up" signified the subject indicated he felt "well". A hand signal of a "thumb down" signified the subject indicated he felt "poorly".

An active cool-down period of walking at a light pace (comfort choice of the subject), on a level treadmill for three minutes was implemented when the LT was discovered. Headgear was removed immediately after the metabolic cart completed data collection. Heart rate and RPE were measured in the last 5 seconds of each minute during the three-minute of the active cool-down stage. Subjects remained in cool-down until the HR stabilized (Franklin, 2000). Also, subjects were allowed to continue walking past three minutes if they desired to do so. When the HR stabilized, passive recovery began with the subject seated. Heart rate was assessed in the last 5 seconds of each minute during the passive cool-down stage. This process continued for a total of five minutes after the active recovery stage (Franklin, 2000). During passive recovery, the researcher and the subject discussed the results of the completed test. The subject was encouraged to ask questions pertaining to the test. In addition, the researcher explained the use of the information and how the VO_2 and the LT were being used in the two tests with the treadmill and the elliptical exercises.

Weeks Four & Five: Administration of VO_2 Workload of the Lactate Threshold

All subjects completed exercise sessions with the elliptical trainer and treadmill at the relative VO_2 corresponding to the LT. The unique VO_2 of the LT for each subject was determined as previously stated. Order of exercise modality was counterbalanced and determined by the choice of the first subject upon arrival to the laboratory. Each subsequent subject alternated exercise modalities during the remaining exercise sessions.

Test duration for both exercise tests was the estimated time for each subject to expend 350 kcal, or until the subject could not continue, whichever occurred first. Reported by the ACSM, a caloric expenditure of 350 kcal is recommended as a typical bout of cardiorespiratory exercise (Franklin, 2000). The amount of time necessary for each subject to expend a total 350 kcal for the duration of these tests was estimated for each subject using metabolic calculations and the mathematical calculation for one-minute caloric expenditure. The one-minute caloric expenditure was based on body weight in kilograms (kg) and the VO_2 associated with each subject's unique VO_2

associated with the LT. This value was then used to estimate the total time in minutes for a total of 350 kcal. This mathematical procedure is found in Appendix B.

The VO_2 associated with the LT was monitored by the metabolic cart. In order to maintain the VO_2 constant, it was necessary to make adjustments to the mechanical workload of both modalities. For the treadmill, metabolic calculations were used to estimate the necessary horizontal ground speed that would elicit the VO_2 associated with the LT. When necessary, adjustments were made in workload by changing the horizontal ground speed of the treadmill only. The treadmill incline was set at eight percent and did not change during the test. Through an unpublished pilot test by Altena (2001), the elliptical machine elicited approximately 33 $ml \cdot kg^{-1} \cdot min^{-1}$ when the resistance was set at 10, the ramp in the center position, and stepping at a cadence of 155 ± 5 steps per minute. This was used as a baseline for estimation of resistance settings for the different VO_2 values of the different subjects (Altena, 2001). No changes were made in the ramp incline or the stepping cadence during this pilot test. Previous research stated exercise biomechanics are similar when comparing treadmill and elliptical exercise when the treadmill is set at an eight percent grade and the elliptical is set at its midpoint position of 10 (Mercer et al., 2001; Bates et al., 1997; Bates, 1995; Bates et al, 1994; Bates, personal communication, September, 29, 2000; Mercer, personal communication, September, 29, 2000).

Additionally, VO_2 drift has been associated with long-duration sub-maximal exercise, and such was the case with a number of the subjects in this research. At a constant mechanical workload, VO_2-drift was reported to occur as quickly as three minutes after heart rate has stabilized. There is less VO_2 drift associated with level treadmill tests compared to downhill running (Robergs et al., 1997). To compensate for the VO_2-drift phenomenon, the VO_2 of each subject was closely monitored in order to maintain the VO_2 corresponding to the LT; thus, the aforementioned adjustments in treadmill horizontal ground speed and elliptical resistance were necessary in some cases.

Two tests were conducted at the VO_2 associated with the LT, one test for each exercise modality.

Elliptical Protocol

A three-minute warm-up using the elliptical trainer began the test session at a resistance setting of five and a step cadence of 155 ± 5 steps per minute. Step cadence was maintained by calibrated metronome that used both visual and auditory indication of the cadence. The ramp of incline was set at 10, which is the midpoint position, and it was not changed during the test. The resistance was estimated for each subject's individualized VO_2, which corresponded to the LT. This estimation was based on the aforementioned, unpublished pilot test, which measured VO_2 at different levels of resistance while stepping at 155 ± 5 at a ramp setting of 10 (Altena, 2001).

To maintain the proper stepping cadence of 155 ± 5 steps per minute was monitored by a calibrated metronome. The electronic display on the elliptical trainer was a guide for the subject to watch for step cadence range. These devices were implemented due to the possibility of error with stepping at an incorrect or inconsistent stepping cadence other than 155 ± 5. If any subject was unable to maintain proper cadence (± 5), the test was terminated.

Measurement of the physiologic variables of HR, VO_2, BLC, and RPE occurred at incremental times of 25%, 50%, 75%, and 100% of the total exercise time for the subject to expend a total of 350 kcal. The data was obtained and recorded in the aforementioned manner. Oxygen-pulse was calculated after the test was completed.

Heart rate measurement occurred continuously using Polar Heart Rate Monitor. Relative VO_2 was measured every 30 seconds by the Quinton Q-Plex 1 metabolic cart. Blood lactate concentration was measured in the final 30 seconds of each quartile measurement point and was evaluated by the Accusport Portable Lactate Analyzer. Heart rate, VO_2, and RPE were recorded in the final five seconds of each stage. Cool-down followed the exercise protocol as previously mentioned.

Treadmill Protocol

A three-minute warm-up on the treadmill was set at a horizontal belt speed of 3.4-3.7 mph. The grade of uphill incline was set at an eight percent grade and it was not changed during the test. The horizontal ground speed was estimated for each subject's individualized VO_2, which corresponded to the LT. This estimation was based upon metabolic calculations. This process was also mentioned earlier. In order to maintain the VO_2 that corresponded to the LT, horizontal ground speed was adjusted based on the VO_2 response of the subject, which was continuously monitored by the Quinton Q-Plex 1 metabolic cart. Time to expend 350 kcal was estimated using the aforementioned process using metabolic calculations.

Assessment of physiologic variables of HR, VO_2, BLC, and RPE occurred at incremental times of 25%, 50%, 75%, and 100% of the total exercise time for the subject to expend a total of 350 kcal. The data was obtained and recorded in the aforementioned manner. Oxygen-pulse was calculated after the test was completed.

Heart rate measurement occurred continuously using Polar Heart Rate Monitor. Relative VO_2 was measured every 30 seconds by the Quinton Q-Plex 1 metabolic cart. Blood lactate concentration was measured in the final 30 seconds of each quartile measurement point and was evaluated by the Accusport Portable Lactate Analyzer. Heart rate, VO_2, and RPE were recorded in the final five seconds of each stage. Cool-down followed the exercise protocol as previously mentioned.

Statistical Analysis

Descriptive statistics were used to characterize the subjects in the research. A 2x4 Repeated Measures Analysis of Variance (REANOVA) was used to compare subject performances in both modalities of exercise using the following dependent variables: Rating of Perceived Exertion (RPE), heart rate, oxygen uptake (VO_2), oxygen-pulse (O_2-pulse) and blood lactate concentration (BLC). A Pearson r correlation was used to evaluate the VO_2 of each quartile of measurement. All statistical analyses were conducted with SPSS for Windows. All hypotheses were tested at the probability of $p<0.05$.

For statistical power of condition main effect, time main effect, and interaction effect of condition x time, a sample size of 18 subjects was necessary (Cohen, 1969).

Small Effect = $F_{1,136}$ Power = 66

Large Effect = $F_{1,136}$ Power = 80

CHAPTER IV

FINDINGS

Chapter IV contains the findings of this research. Descriptive statistics were used to characterize the subjects in this study. Inferential statistics used a Repeated Measures ANOVA describes the main effects of exercise at the LT in the variables of: VO_2, HR, BLC, RPE, and O_2-pulse. A Pearson r Correlation also is used to assess VO_2 at the quartile measurement points. Furthermore, the null hypotheses are either rejected or accepted based on the results of statistical analysis.

Subjects selected for this research were college-age males, ranging from 18 to 24 years of age. All subjects were participating in regular recreational cardiorespiratory exercise for a minimum weekly accumulation of 90 minutes, in a minimum of three exercise sessions per week. Furthermore, subjects also needed to be asymptomatic and healthy, as deemed by the Physical Activity Readiness Questionnaire (PAR-Q) and preliminary health examination. Data was collected from these subjects while exercising at the LT, as predicted by VO_2, on both elliptical and treadmill exercise modalities in a controlled laboratory environment. Based on the inclusion criteria, 20 male volunteers qualified for this research, of which eighteen were able to complete all aspects of the research. Two volunteers were dismissed from testing because of conflicts in testing schedules.

Results

Descriptive Statistics

Ethnicity of the research subjects consisted of 16 white, one African American, and one Asian American. Mean age of this group was 22.39 (±1.33) years old. Mean body weight was 172.31 (±16.81) pounds (78.32 kg). Mean height was 70.39 (±2.01) inches (178.98 cm). Mean predicted VO_2max was 50.35 (±5.08) ml•kg•min^{-1}. Mean VO_2 associated with the LT was 39.25 (±6.45) ml•kg•min^{-1}. A complete listing of descriptive statistics is contained in Table 1.

Table 1

DESCRIPTIVE STATISTIC RESULTS FOR SUBJECTS

Test	Mean	Minimum	Maximum	Std. Dev.	Std. Err.
Age in Years	22.39	20	24	1.33	.31
Height in Inches	70.39	66	75	2.01	.47
Height in Centimeters	178.98	167.6	190.5	5.58	1.31
Weight in Pounds	172.31	150	208	16.81	3.96
Weight in Kilograms	78.32	68.18	94.5	7.63	1.80
Predicted VO_2max	50.74	44.15	58.74	5.08	1.20

Inferential Statistics

Results were analyzed using a 2 x 4 Repeated Measures Analysis of Variance. The priori alpha was set at 0.05. Results are listed below.

Oxygen Consumption. Treadmill VO_2 was significantly ($p<0.05$) greater than elliptical exercise when assessing VO_2 concerning the main effect of condition. No significant differences ($p<0.05$) were observed for the interaction effect of time x condition. Mean VO_2 was 40.149 ml•kg•min^{-1} and 38.392 ml•kg•min^{-1} for treadmill and elliptical exercises, respectively. A complete listing of inferential statistics for VO_2 is contained in Table 2.

Table 2

REPEATED MEASURES ANALYSIS OF VARIANCE FOR OXYGEN CONSUMPTION

Source	SS	df	MS	F	Sig. of F
Condition	111.127	1	111.127	20.32	.000
Error (Condition)	92.972	17	5.469		
Time	69.788	3	23.263	16.666	.000
Error (Time)	71.188	51	1.396		
Condition x Time	4.005	3	1.335	.724	.542
Error (Condition x Time)	94.061	51	1.844		

CONDITION BY TIME

Condition	Time	Mean	Std. Error	Lower	Upper
Treadmill	25%	39.178	1.676	35.641	42.714
	50%	40.511	1.693	36.939	44.083
	75%	40.372	1.591	37.015	43.729
	100%	40.533	1.599	37.161	43.906
Elliptical	25%	36.956	1.307	34.198	39.713
	50%	38.872	1.611	35.473	42.271
	75%	39.067	1.415	36.081	42.053
	100%	38.672	1.478	35.554	41.791

A Pearson r Correlation was also calculated for VO_2 for each measurement point comparing all four-quartile measurement points by condition. Correlations were $r = .891$, $r = .957$, $r = .965$, and $r = .965$ for each respective measurement time of VO_2 compared to the VO_2 of the elliptical and treadmill exercises. A complete listing of the Pearson r Correlations for VO_2 is contained in Table 3.

Table 3

PEARSON r CORRELATION TABLE FOR OXYGEN CONSUMPTION

Paired of VO_2 Measurements	Correlation
25% of Time to Consume 350 kcal	.891
50% of Time to Consume 350 kcal	.957
75% of Time to Consume 350 kcal	.965
100% of Time to Consume 350 kcal	.965

Blood Lactate Concentration. Elliptical exercise had significantly ($p<0.05$) greater BLC than treadmill concerning the main effect of condition. No significant differences ($p<0.05$) were observed for the interaction effect of time x condition. Mean BLC was 5.16 mmol•L and 6.969 mmol•L for treadmill and elliptical exercises, respectively. A complete listing of inferential statistics for BLC is contained in Table 4.

Table 4

REPEATED MEASURES ANALYSIS OF VARIANCE FOR BLOOD LACTATE CONCENTRATION

Source	SS	df	MS	F	Sig. of F
Condition	117.903	1	117.903	18.338	.001
Error (Condition)	109.298	17	6.429		
Time	11.692	3	3.897	2.705	.055
Error (Time)	73.491	51	1.441		
Condition x Time	4.432	3	1.477	1.256	.299
Error (Condition x Time)	59.972	51	1.176		

Table 4 (Continued)

CONDITION BY TIME

Condition	Time	Mean	Std. Error	Lower	Upper
Treadmill	25%	4.911	.453	3.955	5.868
	50%	5.306	.443	4.372	6.239
	75%	5.256	.413	4.385	6.126
	100%	5.167	.453	4.211	6.122
Elliptical	25%	6.383	.527	5.271	7.496
	50%	6.911	.668	5.502	8.320
	75%	7.644	.681	6.209	9.080
	100%	6.939	.609	5.655	8.223

Heart Rate. Elliptical exercise had significantly ($p<0.05$) greater HR than treadmill concerning the main effect of condition. No significant differences ($p<0.05$) were observed for the interaction effect of time x condition. Mean HR was 161.903 beats per minute and 169.208 beats per minute for treadmill and elliptical exercises, respectively. A complete listing of inferential statistics for HR is contained in Table 5.

Table 5

REPEATED MEASURES ANALYSIS OF VARIANCE FOR HEART RATE

Source	SS	df	MS	F	Sig. of F
Condition	1921.361	1	1921.361	11.011	.004
Error (Condition)	2966.389	17	174.493		
Time	2422.056	3	807.352	74.163	.000
Error (Time)	555.194	51	10.886		
Condition x Time	1.806	3	.602	.081	.970
Error (Condition x Time)	379.444	51	7.440		

Table 5 (Continued)

CONDITION BY TIME

Condition	Time	Mean	Std. Error	Lower	Upper
Treadmill	25%	155.333	3.012	148.979	161.688
	50%	162.111	3.632	154.449	169.773
	75%	164.444	3.667	156.708	172.181
	100%	165.722	3.823	157.657	173.787
Elliptical	25%	162.389	2.954	156.156	168.621
	50%	169.222	3.484	161.871	176.574
	75%	172.000	3.126	165.405	178.595
	100%	173.222	3.346	166.164	180.281

Rating of Perceived Exertion. Elliptical exercise had significantly ($p<0.05$) greater RPE than treadmill concerning the main effect of condition. No significant differences ($p<0.05$) were observed for the interaction effect of time x condition. Mean RPE was 12.319 and 13.417 for treadmill and elliptical exercises, respectively. A complete listing of inferential statistics for VO_2 is contained in Table 6.

Table 6

REPEATED MEASURES ANALYSIS OF VARIANCE FOR RATINGS OF PERCEIVED EXERTION

Source	SS	df	MS	F	Sig. of F
Condition	43.340	1	43.340	7.814	.012
Error (Condition)	94.285	17	5.546		
Time	170.688	3	56.896	49.025	.000
Error (Time)	59.187	51	1.161		
Condition x Time	4.188	3	1.396	2.320	.086
Error (Condition x Time)	30.688	51	.602		

Table 6 (Continued)

CONDITION BY TIME

Condition	Time	Mean	Std. Error	Lower	Upper
Treadmill	25%	10.833	.550	9.673	11.993
	50%	12.167	.584	10.934	13.400
	75%	13.000	.605	11.724	14.276
	100%	13.278	.641	11.926	14.630
Elliptical	25%	11.389	.451	10.437	12.341
	50%	13.556	.612	12.265	14.846
	75%	14.056	.563	12.868	15.243
	100%	14.667	.626	13.345	15.988

Oxygen-Pulse. Treadmill exercise had significantly ($p<0.05$) greater O_2-pulse than elliptical concerning the main effect of condition. No significant differences ($p<0.05$) were observed for the interaction effect of time x condition. Mean O_2-pulse was 0.248 ml•kg•min^{-1} and 0.227 ml•kg•min^{-1} for treadmill and elliptical exercises, respectively. A complete listing of inferential statistics for O_2-pulse is contained in Table 7.

Table 7

REPEATED MEASURES ANALYSIS OF VARIANCE FOR OXYGEN-PULSE

Source	SS	df	MS	F	Sig. of F
Condition	1.624	1	1.624	76.930	.000
Error (Condition)	3.588	17	2.110		
Time	1.101	3	3.669	5.706	.002
Error (Time)	3.29	51	6.430		
Condition x Time	1.162	3	3.875	.536	.659
Error (Condition x Time)	3.684	51	7.223		

Table 7 (Continued)

CONDITION BY TIME

Condition	Time	Mean	Std. Error	Lower	Upper
Treadmill	25%	.252	.009	.234	.270
	50%	.250	.008	.234	.266
	75%	.244	.008	.229	.260
	100%	.245	.008	.229	.261
Elliptical	25%	.229	.008	.212	.246
	50%	.229	.008	.211	.247
	75%	.226	.007	.211	.241
	100%	.223	.007	.208	.238

Discussion

Follow up testing for the significantly ($p<0.05$) different main effect of condition was deemed as being improper. The reason for the position concerning the follow up testing was the mathematically estimated time to expend 350 kcal was different for all subjects. This calculation was based on the relative VO_2 that corresponded with the LT and the bodyweight of the subject. Furthermore, subjects exercising for a longer duration may have experienced physiologic phenomenon such as HR drift and/or VO_2 drift. These physiologic phenomena are less likely to occur in short-duration exercise. Brooks et al. (2000) stated prolonged upright exercise at a constant exercise load places an increasing load on the heart. Although the metabolic requirement of the exercise does not change, there is a progressive decrease in venous return of blood to the heart, which would lead to a reduction in stroke volume. This would cause a progressive rise in heart rate in order to maintain cardiac output (Brooks et al., 2000). With these physiologic factors in mind, the validity and accuracy of conducting follow-up testing cannot be assured.

Oxygen consumption by design was to be maintained constant for both exercise conditions. Since a significant difference was observed in VO_2, further explanation is merited. The Pearson r Correlation test was also calculated to show how similar the VO_2 values were at the four quartile measurement points during the 350 kcal treadmill and elliptical exercise tests. This statistical test demonstrated that VO_2 was extremely well correlated when comparing both modalities.

The VO_2 means were also closely related to each other from the perspective of practicality. Elliptical and treadmill VO_2 means were separated by less than 1.8 ml•kg•min^{-1}. In comparison to the mean VO_2 associated with the LT, elliptical VO_2 was lower by 0.86 ml•kg•min^{-1} and treadmill VO_2 was greater than the VO_2 associated with the LT by 0.899 ml•kg•min^{-1}. The total difference in VO_2 between treadmill and elliptical exercise was 1.757 ml•kg•min^{-}1. It is understood that physiologic variables are rarely at a constant level and they might show minor fluctuation over a given measurement period. The range of error for the VO_2 to still be considered maintained constant was $\pm$3.0 ml•kg•min^{-1}. Mean values of VO_2 were 40.149 ml•kg•min^{-1} and 38.392 ml•kg•min^{-1}, respectively for treadmill and elliptical exercises. The mean VO_2 corresponding to the lactate threshold was 39.25 ml•kg•min^{-1}. Based on these VO_2 values, the equivalent VO_2 criteria were maintained during the 350 kcal exercise tests.

During the 350 kcal tests, there was an observed significant difference in BLC between treadmill and elliptical exercise. The higher BLC associated with elliptical exercise might have been influential in changing the other measured variables of HR, O_2-

Pulse, and RPE. Gladden (2000) stated lactate exchange might be enhanced when blood flow is increased. Blood flow and its optimal distribution are theoretically of great importance in net lactate exchange among bodily tissues. In the case of net lactate uptake, if all other factors remain constant, an increased blood flow should increase lactate and proton delivery to the muscle, thereby maintaining more favorable extracellular to intracellular lactate and proton gradients; thus, promoting net lactate uptake (Gladden, 2000). This observation by Gladden (2000) may indicate the rationale for the increased HR resulting from the increased BLC. Blood flow through the body could be increased through an increased heart rate, causing the lactate exchange among the tissues for lactate oxidation. The lower associated blood pH observed in the elliptical exercise might have been influential in the central control of heart rate, which would have caused blood flow to increase in order to improve lactate distribution and uptake. The higher HR observed in the elliptical exercise was accompanied by an elevated BLC. These variables were observed to be significantly ($p<0.05$) greater during elliptical exercise compared to treadmill.

Borg (1982) observed a relationship between BLC and RPE. It was concluded that an integration of central factors, such as heart rate, and peripheral factors such as blood lactate, would explain the psychophysical variation better than any single physiologic factor (Borg, 1982). Borg's statement defined that an individual's perception of effort is not tied to only one factor, but RPE is influenced by many variables, both centrally focused and peripherally located. In addition, Borg (1982) stated the signals that influence RPE are received from the working muscles and joints, the central nervous system, cardiovascular functioning, and respiratory functioning (Borg, 1982).

Furthermore, localized lactate accumulation causes the perception of pain, thus influencing the perception of effort. Guyton & Hall (1996) state that pain occurs when ischemic conditions are present in skeletal muscles, like in the case during intense exercise, like in the case of exercise at or beyond the LT. It is possible that other chemical agents, such as bradykinin and proteolytic enzymes, are formed in the tissues because of cellular damage and that these, along with lactate stimulate the pain received by the nerve endings (Guyton et al., 1996). The acidic environment, associated with lactate accumulation, influences individuals RPE due to the perception of localized muscular pain and the increase in ventilation, which also results due to lactate accumulation.

In summary, the results of this research observed elliptical exercise to be less efficient when assessing the physiologic responses that were observed when subjects exercised at the same VO_2. Variables that characterized exercise efficiency were: 1) HR, 2) O_2-pulse, 3) BLC, and 4) RPE. Even when VO_2 was arguably identical, the observed results from subjects exercising in the elliptical modality displayed a higher HR, greater BLC, and an elevated RPE. A direct measurement of cardiorespiratory efficiency was the variable of O_2-pulse. The elliptical exercise modality observed lower cardiorespiratory efficiency with a lower measurement of O_2-Pulse compared to treadmill exercise. Furthermore, caloric expenditure is closely related to VO_2. Therefore it can be concluded from these results that treadmill exercise is the optimal choice for cardiorespiratory training and caloric expenditure. However, the observed statistical significance differences between treadmill and elliptical exercise would be minimal from a practical standpoint. These results do not indicate that elliptical exercise is not effective. Elliptical exercise is proficient in eliciting a HR and VO_2 intensity that would cause cardiorespiratory training effects. Also the elliptical is effective in caloric expenditure. It is speculated that elliptical exercise would be more efficient than cycling in caloric expenditure because the subject has to support his/her own bodyweight with the elliptical modality.

CHAPTER V

FINDINGS, CONCLUSIONS, AND RECOMMENDTATIONS

Summary of Findings

The findings of this study indicate the elliptical exercise as being less efficient than treadmill exercise. Subjects perceived elliptical as being more difficult to execute than treadmill exercise while exercising at the VO_2 of the LT. Furthermore, physiologic variables of HR, BLC, and O_2-pulse indicated the elliptical exercise to be significantly ($p<0.05$) less efficient than treadmill exercise, even when VO_2 was maintained constant in both modalities.

Statistical significance places a shadow over the practical significance of this research. The observed significantly ($p<0.05$) different main effect means of condition should be evaluated very carefully in the interpretation of the values collected because of their practical similarity. The practicality and application of these results cannot be overlooked The following sections are devoted to stating reasons why statistical differences might have been observed. Speculated practical application of the observed differences is also offered to further explain the observed differences between elliptical and treadmill exercises.

Oxygen Consumption (VO_2)

By the design of this research, VO_2 of both 350 kcal tests in treadmill and elliptical exercise were maintained at the lactate threshold (LT) for each subject. The amount of error allowed during the tests was $\pm$3 ml•kg•min^{-1}. The VO_2 associated with the LT was unique to each subject's level of fitness and the mode(s) of training. Statistical analysis compared the total sample group as a whole. The main effect means for condition measuring VO_2 comparing elliptical and treadmill exercise were separated by only 1.757 ml•kg•min^{-1}. Treadmill VO_2 was significantly ($p<0.05$) greater than the VO_2 of elliptical exercise. The 350 kcal test observed the elliptical VO_2 lower than the associated LT by 0.86 ml•kg•min^{-1}. In the same test, treadmill VO_2 was greater than the VO_2 associated with the LT by 0.899 ml•kg•min^{-1}. From the perspective of practicality, VO_2 means are not just closely related to each other, but the means are nearly identical. A Pearson r Correlation was calculated to evaluate the relationship of the VO_2 observed in the 350 kcal tests. Oxygen consumption of treadmill and elliptical exercise were closely related at each of the quartile measurement points. Pearson r correlation data reflected correlations during all four quartiles of measurement by condition. At 25% of the total estimated time to consume 350 kcal, $r = .891$. At 50% of the total estimated time to consume 350 kcal, $r = .957$. At 75% of the total estimated time to consume 350 kcal, $r = .965$. At 100% of the total estimated time to consume 350 kcal, $r = .965$. The observed Pearson r correlations display the closely related nature of VO_2 with the two exercise modalities during the 350 kcal exercise tests.

In summary concerning VO_2, no appreciable difference was observed between the main effect means in VO_2 in elliptical and treadmill exercise. This stance is taken because biological factors, such as VO_2, are never maintained at a constant rate, even when a constant mechanical workload is applied. Even when measuring with a metabolic cart, VO_2 fluctuated during constant-load tests. When the fluctuations occurred, the aforementioned adjustments in either elliptical resistance or treadmill horizontal ground speed were applied accordingly. The parameters for the 350 kcal test with the elliptical and treadmill were maintained within 1.757 $ml \cdot kg \cdot min^{-1}$, which was also within the ± 3 $ml \cdot kg \cdot min^{-1}$ given for error. Mechanical workloads were adjusted to maintain the VO_2 of the LT constant, and that was executed within the parameters set up by the design of the study.

Heart Rate

During the 350 kcal exercise tests, elliptical exercise elicited a significantly ($p<0.05$) greater HR compared to treadmill exercise. This occurred even when VO_2 was maintained at the aforementioned desired level of ± 3 $ml \cdot kg \cdot min^{-1}$ in both exercise tests. Elliptical HR averaged 7.31 beats per minute more than treadmill HR. This was calculated by averaging the differences in modality heart rates associated with the quartile points of measurement. The difference in HR might be caused by two speculated factors. First, blood flow might have been impeded due to the duration of muscular contraction. Elliptical exercise might have an associated muscular contraction that is longer duration than treadmill exercise. As stated earlier, the biomechanics of the elliptical and treadmill were not identical, but were based on previous research that stated the biomechanics were similar (Mercer et al., 2001). Second, the elliptical exercise return phase, when the leg leaves the tow-off position and returns to the heel strike position, might not be as passive as what might have been previously assumed. The difference in HR might also be an indication that blood flow might be reduced in comparison due to a greater eccentric muscular contraction associated with elliptical exercise, also due to attributed biomechanical differences between treadmill and elliptical exercise. The eccentric contraction might be causing a reduction in cardiac output by causing extra resistance on the arterial side of the heart; thus, the heart has to pump with greater contractile force in order to eject the stroke volume required to maintain cardiac output for that mechanical workload of exercise (Thomas, personal communications, April 29, 2001). Kolkhorst et al. (1996) discovered the eccentric muscular action of running downhill elicited a significantly ($p<0.05$) greater HR compared to uphill and level treadmill running even when VO_2 was maintained constant across the different treadmill tests (Kolkhorst et al., 1996). The results of Kolkhorst et al. (1996) are closely associated with the results of the present research. It is speculated that elliptical exercise demanded a greater eccentric muscular contraction than treadmill exercise. Based on the previous research by Kolkhorst et al. (1996), the eccentric muscular demand caused a significantly ($p<0.05$) greater HR even though VO_2 was maintained equivalent in treadmill and elliptical exercise.

Blood Lactate Concentration

Elliptical exercise observed a significantly ($p<0.05$) greater BLC when compared to treadmill exercise. This occurred even when VO_2 was maintained at the aforementioned desired level ±3 ml•kg•min^{-1} for both exercise tests. The elliptical exercise averaged 1.81 mmol•L^{-1} greater than treadmill exercise. This was calculated by averaging the differences in modality heart rates associated with the quartile points of measurement. As mentioned earlier in the discussion about HR and the eccentric muscular contraction, speculated to be more apparent in elliptical exercise than treadmill, differences in BLC might also be a result from the occluded in blood flow. Lactate is a result of the anaerobic breakdown of carbohydrates and is directly responsible for the change in blood pH. The blood pH change demonstrates the blood is more acidic. In this acidic environment, exercise would eventually have to be terminated. A reason for the elevated BLC is also associated with the previous statements concerning HR. Speculated to be greater in elliptical exercise than treadmill, the eccentric muscular contraction may have created the demand for the anaerobic system in the elliptical exercise. The muscular contraction would impede blood flow to the active tissues, therefore causing glycolysis to occur in order to maintain the VO_2 of the LT. Previous research by Miles et al. (1980) discovered cycling elicited greater BLC than treadmill exercise when VO_2 was maintained at a constant level for both modalities. The BLC results of Miles et al. (1980) along with the BLC results of this study might be an indication that elliptical exercise might be more like cycling than it is like treadmill exercise. However, the elliptical modality is different than cycling because the elliptical is executed with the subject supporting their own bodyweight, which is also the case with treadmill exercise. Mercer et al. (2001) found no differences between elliptical and treadmill modalities when assessing VO_2max and maximal HR. However, the present research observed glycolysis to be greater in elliptical exercise compared to treadmill exercise while exercising at the LT and VO_2 was maintained constant in both modalities.

Rating of Perceived Exertion

Elliptical exercise elicited a significantly ($p<0.05$) higher RPE when compared to treadmill exercise. This was observed even when VO_2 was maintained at the aforementioned desired level ± 3 ml•kg•min^{-1} for both exercise tests. This indicates that elliptical exercise was perceived as being more difficult to the subjects when compared to treadmill exercise. However, one cannot assume that a RPE is at accurate as the other physiologic variables measured in this research. Moreau et al. (1999) stated RPE could be used as an adjunct marker for physiologic stress during exercise, but there appears to be considerable inter-individual variability in RPE ratings, especially when correlating RPE with BLC. Moreau et al. (1999) suggested RPE should be used only as a surrogate marker for physiologic exercise intensity because of the variability in the interpretation of exercise effort the effort's relationship to maximal effort performance. The LT has been documented to occur at an RPE of 13-15. The current study also observed the aforementioned variability associated with RPE, even when the subjects fully understood how the scale was designed to work. However, the RPE values did show agreement that the higher BLC of elliptical exercise also had a higher RPE. It is speculated the elevated

BLC associated with elliptical exercise may have been influential in increasing the perception of effort; thus the RPE of elliptical exercise was significantly ($p<0.05$) greater than treadmill. The mean values of RPE from the quartile measurement points should be evaluated from the practical perspective, too. Mean elliptical RPE was 13.42. Mean treadmill RPE was 12.32. A rating of "12" falls between a rating of "Fairly light" and a rating of "13" is "Somewhat Hard". As far as the meaning of RPE, subjects rated the elliptical as being more difficult to perform than treadmill exercise.

Oxygen-Pulse

Treadmill exercise had a significantly ($p<0.05$) higher O_2-pulse calculation when compared to elliptical exercise. This occurred even when VO_2 was maintained at the aforementioned desired level ± 3 ml•kg•min^{-1} for both exercise tests. Elliptical mean O_2-pulse was .2267. The mean O_2-pulse for treadmill was .2479. These values are closely related to each other, but the results of this research observed greater efficiency with treadmill exercise compared to elliptical. This calculation is associated VO_2 divided by the associated HR. This was completed only at the quartile measurement points in the 350 kcal tests. Since the HR was greater during elliptical exercise, and the VO_2 was maintained as equal across both modalities, the elliptical exercise would be observed as being less efficient than treadmill exercise. This means that treadmill exercise is more efficient than elliptical exercise, when using the observed data collected in this research. Pannier et al. (1980) observed trained runners to have significantly ($p<0.05$) different O_2-pulse between treadmill and cycle exercise in when comparing treadmill and cycle ergometry. This research found the O_2-pulse of trained runners to be greater with treadmill compared to cycling (Pannier et al., 1980). Based on the results of this research and the results of Pannier et al. (1980), treadmill exercise appears to be most efficient compared to elliptical and cycling exercises.

Conclusions

Based on the results of the 350 kcal tests at the VO_2 of the LT, statistical findings consistently indicated treadmill exercise as being more efficient than elliptical exercise. At comparable VO_2, elliptical exercise was found to have significantly greater HR and BLC and a lower O_2-pulse in comparison to treadmill exercise. Subjects also perceived elliptical exercise as requiring more effort than treadmill exercise. However, practical application of this research would state there is little difference in the elicited cardiorespiratory variables and caloric expenditure between the modalities. The treadmill's observed efficiency compared to elliptical might be overshadowed by the non-impact exercise the elliptical modality offers. Therefore, both elliptical and treadmill are sufficient for increasing fitness levels, improving cardiorespiratory efficiency, and for adequate caloric expenditure. Both modalities sufficiently increase HR and VO_2. Both modalities also employ the major muscles of the body with the subject supporting his/her own bodyweight, and both modalities can also be used at varying mechanical intensities and can be used for extended periods of time.

Recommendations

1. A longer warm-up time is recommended prior to exercise data collection. This research used a three-minute warm-up. A longer timeframe would reduce the possibility of VO_2 overshoot in the first quartile measurement. A 10-minute warm-up was recommended (Thomas, personal communications 05-04-01).
2. Conducting a series of tests to assess the LT is recommended to ensure the accuracy of the VO_2 associated with the LT. It is also recommended to conduct LT tests with each modality
3. It is recommended to conduct a series of 350 kcal tests with both modalities of exercise in order to test the reliability of data collection.
4. The rise over run principle is recommended to equate horizontal and vertical workloads so both mechanical workloads are the same rather than maintaining a constant step cadence of (155 ± 5) with the elliptical.
5. The recommendation is to assume that a difference does actually exist between elliptical and treadmill exercise in creating a metabolic calculation. This research used metabolic calculations as caloric expenditure estimations for both modalities of exercise.
6. A venous sample recommended for the assessment of BLC rather than the capillary sample used in this research.
7. It is recommended to conduct practice sessions with the exercise modalities with the researcher present to evaluate and coach the subject.

REFERENCES

Allen W. K., Seals, D. R., Hurley, B. F., Ehsani, A. A., and Hagberg, J. M. (1985). Lactate threshold and distance running performance in young and older athletes. Journal of Applied Physiology (58), 1281-1284.

Altena, T. S (2001). [Pilot study with the EFX546 to determine VO_2 at varying mechanical workloads]. Unpublished raw data.

Bates, B. T., & Mercer, J. A. (1994). [Miller Walker Report]. Unpublished raw data.

Bates, B. T. (1995). [EFX evaluation at four elevation settings]. Unpublished raw data.

Bates B. T. (personal communication, September, 29, 2000).

Bates B. T. & Mercer, J. A. (1997). [Metabolic cost of exercising at different workloads on the transport]. Unpublished raw data.

Beaver, W. L., Wasserman, K., and Whipp, B. J., (1985). Improved detection of lactate threshold during exercise using a log-log transformation. Journal of Applied Physiology (59), 6, 1936-1940.

Bellew, K. M., Burke, E. J., and Jensen, B. E. (1983). Ratings of perceived exertion at anaerobic threshold in males and females. Abstracts of Research Papers. Reston VA: AAHPERD.

Beneke, R. (1995). Anaerobic threshold, individual anaerobic threshold, and maximal lactate steady state in rowing. Medicine and Science in Sports and Exercise (27), 863-867.

Beneke, R., Hutler, M., & Leithanhauser, R. M. (2000). Maximal lactate-steady-state independent of performance. Medicine and Science in Sports and Exercise (32), 6, 1135-1139.

Beneke, R., & Von Duvillard, S. P., (1996). Determination of maximal lactate steady state response in selected sports events. Medicine and Science in Sports and Exercise (28), 241-246.

Birrell, J. (personal communication, October, 1, 2000).

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. Scandinavian Journal of Rehabilitative Medicine (2), 92-98.

Borg, G. A. V., (1982). Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise (5), 377-381.

Boutcher, S. H., Seip, R. L., Hetzler, R. K., Pierce, E. F., Snead, D., and Welman A. (1989). The effects of specificity of training on rating of perceived exertion at the lactate threshold. European Journal of Applied Physiology (59), 365-369.

Brooks, G. A. (2000). Intra- and extra-cellular lactate shuttles. Medicine and Science in Sports and Exercise (32), 4, 790-799.

Brooks, G. A., Fahey, T. D., White, T. P., & Baldwin, K. M. (2000). Exercise Physiology: Human Bioenergetics and Its Application (3rd edition). Mountain View, CA: Mayfield Publishing Company.

Cafafelli, E., (1982). Peripheral contributions to the perception of effort. Medicine and Science in Sports and Exercise (14), 382-389.

Carter, H.; Jones, A. M.; and Doust, J. H. (1999). Effect of incremental test protocol on lactate minimum speed. Medicine and Science in Sports and Exercise (31), 837-845.

Carton R. L., and Rhodes, E. C. (1985). A critical review of the literature on ratings of perceived exertion. Sports Medicine (2), 198-222.

Ceci, R., and Hassmen, P. (1991). Self-monitored exercise at three different rpe intensities in treadmill vs. field running. Medicine and Science in Sports and Exercise (23), 5,732-738.

Coggan, A. R., Spina, R. J., Kohrt, W. M., & Holloszy, J. O., (1993). Effect of prolonged exercise on muscle citrate concentration before and after endurance training in men. American Journal of Physiology (264), E215-E220.

Cohen, J. (1969). Power Analysis for the Behavioral Sciences. Academic Press: New York, London.

Demello, J. J., Cureton, K. J., Boineau, R. E., and Singh, M. M. (1987). Ratings of perceived exertion at the lactate threshold in trained and untrained men and women. Medicine and Science in Sports and Exercise (19), 4, 354-362.

Dirckx, J. H. (Ed.). (1997). Steadman's concise medical dictionary for the health professions (3rd ed.). Baltimore: Williams & Wilkins.

Donovan, C. M., and Pagliassotti, M. J. (2000). Quantitative assessment of pathways for lactate disposal in skeletal muscle fiber types. Medicine and Science in Sports and Exercise (32), 4, 772-777.

Donovan, C. M., and Pagliassotti, M. J. (1990). Enhanced efficiency of lactate removal after endurance training. Journal of Applied Physiology (68), 1053-1058.

Edwards, R. H. T., Melcher, A., Hesser, C. M., Wigertz, O., & Eklund, L. G. (1972). Physiological correlates of perceived exertion in continuous and intermittent exercise with the same average power output. European Journal of Clinical Investigation (2), 108-114.

Eston, R. G., Davies, B. L., & Williams, J. G. (1987). Use of perceived effort ratings to control exercise intensity in young healthy adults. European Journal of Applied Physiology (56), 222-224.

Ekblom, B., & Goldbarg, A. N. (1971). The influence of physical training and other factors on the subjective rating of perceived exertion. Acta Physiologica Scandinavica (83), 399-406.

Farrell, P. A., Wilmore, J. H., Coyle, E. F., Billing, J. E., & Costill, D. L. (1979). Plasma lactate accumulation and distance running performance. Medicine and Science in Sports and Exercise (11), 338-334.

Faulkner, J. A., Roberts, D. E., Elk, R. L., & Conway, J. (1971). Cardiovascular responses to sub maximum and maximum effort cycling and running. Journal of Applied Physiology (30), 457-461.

Fell, J. W., Rayfield, J. M., Gulbin, J. P., and Gaffney, P. T. (1998). Evaluation of the Accusport Lactate Analyzer. International Journal of Sports Medicine, 19, 199-204.

Foxdall, P., Sjodin, A., & Sjodin, B. (1996). Comparison of blood lactate concentrations obtained during incremental and constant intensity exercise. International Journal of Sports Medicine, 17, 360-365.

Franklin, B.A. (Ed.). (2000). American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (6th ed.): Philadelphia, PA: Lippincott Williams & Wilkins.

Gladden, (2000). The role of skeletal muscle in lactate exchange during exercise: Introduction. Medicine and Science in Sports and Exercise (32), 4, 753-755.

Gladden, B. L. (2000). Muscle as a consumer of lactate. Medicine and Science in Sports and Exercise (32), 4, 764-771.

Glass, S. C., Knowlton, R. G., & Becque, M. D. (1991). Perception of effort during high-intensity exercise at low, moderate, and high wet bulb globe temperatures. European Journal of Physiology (68), 519-524.

Guyton, A. C., Hall, J. E., (1994). Textbook of Medical Physiology (9th edition). Philadelphia, PA: Saunders.

Hagberg, H. A.; Mullin, J. P.; & Nagle, F. J. (1978). Oxygen consumption during constant-load exercise. Journal of Applied Physiology (45), 381-384.

Haskivts, E. M., Seip, R. L., Welman, J. Y., Rogol, A. D., and Welman, A. (1992). The effect of training intensity on ratings of perceived exertion. International Journal of Sports Medicine (13), 377-383.

Heck, H., Mader, A., Hess, G., Mucke, S. Muller, R., and Hollman, W. (1985). Justification of the 4-mmol•L lactate threshold. International Journal of Sports Medicine (6), 117-130.

Hellerstein, H., and Franklin, B. (1984). Exercise Testing and Prescription In: Rehabilitation in the Coronary Patient. New York: Wiley.

Henrizte, J., Welman, A., Schurrer, R. L., and Barlow, K. (1985). Effects of training at and above the lactate threshold on the lactate threshold and maximal oxygen uptake. European Journal of Physiology (54), 84-88.

Hermansen, L. (1973). Oxygen transport during exercise in human subjects. Acta Physiologica Scandinavica Supplement (399), 1-104.

Hermansen, L, Ekblom, B., & Saltin, B., (1970). Cardiac output during sub maximal and maximal treadmill and cycle exercise. Journal of Applied Physiology (29), 82-86.

Hetzler, R. K., Seip, R. L., Boucher, S. H., Pierce, E., Snead, D., and Welman, A., (1991). Effects of exercise modality on ratings of perceived exertion at various lactate concentrations. Medicine and Science in Sports and Exercise (23), 88-92.

Hagberg, J. M., Giese, M. D., & Schneider, R. B. (1978). Comparison of the trhree procedures for measuring VO2max in competitive cyclists. European Journal of Applied Physiology (39), 47-52.

Hughson, R. L., Cochrane, J. E., and Butler, G. C., (1993). Faster oxygen uptake kinetics at the onset of supine exercise with and without lower body pressure. Journal of Applied Physiology (75), 5, 1962-1967.

Jansson, E., and Kaijser, L. (1987). Substrate utilization and enzymes in skeletal muscle of extremely endurance-trained men. Journal of Applied Physiology (662), 999-1005.

Jones, N. L., Ehrsam, R. E. (1984). Dyspnea in exercise. Medicine and Science in Sports and Exercise (16), 14-19.

Jones, A. M., Doust, J. H., (1998). The validity of the lactate minimum test for determination of the maximal lactate steady state and physiological correlates to 8 km running performance. Medicine and Science in Sports and Exercise (30), 1304-1313.

Kindermann, W., Simon, G., & Keul, J., (1979). The significance of the aerobic-anaerobic transition for the determination of workload intensities during endurance training. European Journal of Applied Physiology (42), 25-34.

Kiens, B. (1997). Effect of endurance training on fatty acid metabolism: Local adaptations. Medicine and Science in Sports and Exercise (29), 640-645.

Kolkhorst, F. W., Mittelstadt, S. W., & Dolgener, F. A. (1996). Perceived exertion and blood lactate concentration during graded treadmill running. European Journal of Applied Physiology (72), 272-277.

Koyal, S. N., Whipp, B. J., Huntsman, D., Bray, G. A., & Wasserman, K. (1976). Ventilatory responses to the metabolic acidosis of treadmill and cycle ergometry. Journal of Applied Physiology (40), 864-867.

Kravits, L.; Robergs, R. A.; Heyward, V. H.; Wagner, D. R.; Powers, K. (1997). Exercise mode and gender comparisons of energy expenditure at self- selected intensities. Medicine and Science in Sports and Exercise (29), 8, 1028-1035.

Loggen, H., Graham, T., & Sjogaard, G. (1980). Muscle metabolites, force, and perceived exertion bicycling at various pedaling rates. . Medicine and Science in Sports and Exercise (12), 345-351.

Mader, A., Leisen, H., and Heck, H., (1976). Determination of sport specific endurance capacity in the laboratory. Sport Medicine (5), 109-112.

Mader, A., Leisen, H., and Heck, H. (1986). A theory of the metabolic origin of the "anaerobic threshold." International Journal of Sports Medicine (7), 45-65.

McArdle, W. D., Katch, F. I., Katch, V. L. (1996). Exercise Physiology: Energy, Nutrition and Human Performance (4^{th} edition). Baltimore, MD: Williams & Wilkins.

McKay, G. A., and Banister, A. (1976). A comparison of maximum oxygen uptake determination by cycle ergometry at various pedaling frequencies and by treadmill running at various speeds. European Journal of Applied Physiology (35), 191-200.

Mercer, J. A. (personal communication, September, 29, 2000).

Mercer, J. A. (personal communications February, 1 2001).

Mercer, J. A., Dufek, J. S., Bates, B. T. (2001). Analysis of peak oxygen consumption and heart rate during elliptical and treadmill exercise. Journal of Sports Rehabilitation (10), 48-56.

Mihevic, P. M. (1981). Sensory cues for perceived exertion: A review. Medicine and Science in Sports and Exercise (13), 150-163.

Miles, D. S., Critz, J. B., & Knowlton, R. G., (1980). Cardiovascular, metabolic, and ventilatory responses of women to equivalent cycle ergometer and treadmill exercise. Medicine and Science in Sports and Exercise (12), 1, 14-19.

Mongnoni, P., Sirtori, M. D., Lorenzelli, F., & Cerretelli, P., (1990). Physiological responses during prolonged exercise at the power output corresponding to the blood lactate threshold. European Journal of Applied Physiology (60), 239-243.

Moreau, K. L.; Whaley, M. H.; Ross, J. H.; & Kaminsky, L. A., (1999). Effects of blood lactate concentration on perception of effort during graded and steady state treadmill exercise. International Journal of Sports Medicine (20), 269-274.

Nardone, A., Romano, C., & Schieppati, M. (1989). Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening or active muscles. Journal of Physiology (409), 451-471.

Nardone, A., & Schieppati, M. (1988). Shift of activity from slow to fast muscle during voluntary lengthening contractions of the triceps surae muscles in humans. Journal of Physiology (395), 363-381.

Nobel, B. J., (1982). Preface to the symposium on recent advances in the study and clinical use of perceived exertion. Medicine and Science in Sports and Exercise (14), 5, 376.

Oyono-Enguelle, S, Marbach, J, Heitz, (1990). Lactate removal ability and graded exercise. Journal of Applied Physiology (68), 901-911.

Pandolf, K. B., Kamon, E., & Noble, B. J. (1978). Perceived exertion and physiological responses during negative and positive work in climbing a laddermill. Journal of Sports medicine and Physical Fitness (18), 277-236.

Pannier, J. L., Vrijens, J., & Van Cauter, C. (1980). Cardiorespiratory response to treadmill and cycle exercise in runners. European Journal of Allied Physiology (43), 243-241.

Pfitzinger, P. & Freedson, P. S. (1998). The reliability of lactate measurements during exercise. International Journal of Sports Medicine (19), 349-357.

Phillips, S. M., Green, H. J., Tarnapolsky, M. A., Heigenhauser, J. F., Hill, R. E., and Grant, S. M. (1996). Effects of training duration on substrate turnover and oxidation during exercise. Journal of Applied Physiology (81), 2182-2191.

Potteiger, J. A., & Evans, B. W. (1994). Using heart rate and ratings of perceived exertion to monitor intensity in runners. Journal of Sports Medicine and Physical Fitness (35), 181-186.

Robergs R. A., Roberts, S. O. (1997). Exercise Physiology: Exercise Performance, and Clinical Applications. St. Louis, MO: Mosby.

Robertson, R. J., (1982). Central signals of perceived exertion during dynamic exercise. Medicine and Science in Sports and Exercise (14), 390-396.

Rowell, L. B. (1988). Muscle blood flow in humans: how high can it go? Medicine and Science in Sports and Exercise (29), S97-103.

Seip, R. L., Snead, D., Pierce, E. F., Stein, P., and Welman, A., (1991). Perceptual responses and blood lactate concentration: Effect of training state. Medicine and Science in Sports and Exercise (23), 80-87.

Saldin, K. S., Van Wynsberghe, D., (1998). Anatomy and Physiology: The Unity of Form and Function, Second Edition. New York, NY: McGraw-Hill.

Stainsby, W. N., and Brooks, G. A., (1990). Control of lactic acid in contracting muscles during exercise. Exercise and Sport Science Review (18), 29-63.

Snyder, A. C, Woulfe, T, Welsh, R., & Foster, C, (1994). A simplified approach to estimating the maximal lactate steady state. International Journal of Sports Medicine (15), 27-31.

Sjodin, B, Jacobs, I., and Karlsson, J., (1979). Onset of blood lactate accumulation and enzyme activities in muscle vastus lateralis in man. International Journal of Sports Medicine (2), 166-170.

Spranger, L. L. (1998). A comparison of the physiological responses to exercise on five different upper and lower body ergometers (Master's Thesis, University of Wisconsin—La Crosse, 1998). Microform Publications, Eugene, OR.

Stamford, B. A., & Nobel, B. J. (1974). Metabolic cost and perception of effort during cycle ergometer work performance. Medicine and Science in Sports and Exercise (6), 226-231.

Steed, J., Gaesser, G. A., and Weltman, A. (1994). Rating of perceived exertion and blood lactate concentration during sub-maximal running. Medicine and Science in Sports and Exercise (26), 797-803.

Stegmann, H., Kinderman, W., Schnable, A. (1981). Lactate kinetics and individual anaerobic threshold. International Journal of Sports Medicine (2), 160-165.

Stoudemire, N. M., Weidman, L., Pass, K. A., McGinnes, C. L., Gaesser, G. A., and Weltman, A. (1996). The validity of regulating blood lactate concentration during running by ratings of perceived exertion. Medicine and Science in Sports and Exercise (28), 4, 490-495.

Taylor, C. R., (1989). Structural and functional limits to oxidative metabolism: Insights from scaling. Annual Review of Physiology (49), 135-146.

Tegtbur, U., Busse, M. W., and Braumann, K. T. M., (1992). Estimation of an individual equilibrium between lactate production and catabolism during exercise. Medicine and Science in Sports and Exercise (25), 620-627.

Thomas, C. T. (1970). Taber's Cyclopedic Medical Dictionary (12th ed.). Philadelphia: F. A. Davis Company.

Thomas, T. R., personal communications, April 29, 2001

Thomas, T. R., Ziogas, G., Smith, T., Zhang, Q., & Londree, B. R. (1995). Physiological and perceived exertion responses to six modes of sub maximal exercise. Research Quarterly in Exercise and Sport (66), 239-245.

Thomas, T. R., Feiock, C. W., & Araujo, J., (1989). Metabolic responses associated with four modes of prolonged exercise. The Journal of Sports Medicine and Physical Fitness (26), 1, 77-82.

Thompson, D. L., & West, K. A. (1998). Ratings of perceived exertion to determine intensity during outdoor running. Canadian Journal of Applied Physiology (23), 56-65.

Toner, M. M., Glickman, E. L., & McArdle, W. D. (1990). Cardiovascular adjustments to exercise distributed between the upper and lower body. Medicine and Science in Sports and Exercise (20), 773-778.

Turcotte, L. P., Richter, A., and Kiens, B. (1992). Increased plasma free fatty acid uptake and oxidation during prolonged exercise in trained vs. untrained humans. American Journal of Physiology (262), E971-E799.

Urhausten, A., Coen, B., Weiler, B, Kinderman, W. (1993). Individual anaerobic threshold and maximum lactate steady state. International Journal of Sports Medicine (14), 134-139.

Weltman, A., Snead, D., & Seip, L. (1996). Reliability and validity of a continuous incremental treadmill protocol for the determination of lactate threshold, fixed blood concentrations, and VO2max. International Journal of Sports Medicine (11), 26-32.

Van Den Burg, M. T. C., & Ceci, R. (1986). A comparison of a psychophysical estimation and a production method in a laboratory and field condition. The Perception of Physical Work (46), 35-46.

Welman, A. (1995). The Blood Lactate Response to Exercise. Champaign, IL: Human Kinetics.

Weltman, J. Y., Kanaley, J. A., Rogol, A. D., Hartman, M. L., Veldhuis, J. D. & Weltman, A. (1997). Repeated bouts of exercise alter the blood lactate (HLa)-ratings of perceived exertion (RPE) relationship. Medicine and Science in Sports and Exercise (29), S215.

Westerlind, K. C.; Byrnes, W. C.; & Mazzeo, R. S. (1992). A comparison of the oxygen drift in downhill vs. level running. Journal of Applied Physiology (72), 796-800.

Whaley, M. H., Woodall, M. T., Kiminsky, L. A., & Emmett, J. D. (1997). Reliability of perceived exertion during graded exercise testing in apparently healthy adults. Journal of Cardiopulmonary Rehabilitation (17), 37-42.

Whipp, B. J., & Wasserman, K., (1972). Oxygen uptake kinetics for various intensities of constant-load work. Journal of Applied Physiology (33), 3, 351-356.

Yeh, M. P., Garfner, R. M., & Adams, T. D. (1983). Anaerobic Threshold: problems of determination and validation. Journal of Applied Physiology (55), 4, 1178-1186.

Wiswell R. A., & deVries, H. A. (1979). Time course of O2-pulse during various tests of aerobic power. . European Journal of Physiology (41), 221-31.

Yoshida, T. Chida, M., Ichioka, M., & Suda, Y. (1987). Blood lactate parameters related to aerobic capacity and endurance performance. European Journal of Physiology (56), 7-11.

Yoshida, T., (1984). Effect of exercise duration during incremental exercise on the determination of anaerobic threshold and the onset of blood lactate accumulation. European Journal of Physiology (53), 196-199.

Zeni, A. I., Hoffman, M. D., & Clifford, P. S., (1996). Energy expenditure with indoor exercise machines. Journal of the American Medical Association (275), 1424-1427.

APPENDIX A

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

Answer "yes" or "no" to each question.

1. _____ Has a physician ever said you have a heart condition and recommended activity with medical supervision?
2. _____ Do you have chest pain brought on by physical activity?
3. _____ Have you developed chest pain in the past month?
4. _____ Do you tend to lose consciousness or fall over as a result of dizziness?
5. _____ Do you have a bone or joint problem that may be aggravated by physical activity?
6. _____ Do you have a heart murmur or abnormal heart rhythm (arrhythmia)?
7. _____ Do you experience fatigue or shortness of breath during rest or with usual, light activity?
8. _____ Do you experience pain(s) in the legs when you walk normal distances?
9. _____ Do you use tobacco product(s) of any kind?
10. _____ Do you suffer from elevated blood pressure (hypertension: $\geq$ 140/90 mm hg) or are you currently taking anti-hypertensive medication?
11. _____ Do you have a metabolic disease (Diabetes; Gout; Kidney, Liver, or Thyroid Diseases)
12. _____ Do you suffer from Asthma, particularly that which is exercise induced?
13. _____ Do you have or have you recently been treated for an infection?
14. _____ Are you experiencing any significant emotional distress?
15. _____ Are you currently taking any medication, prescription or otherwise?
19. _____ Do you have a chronic infectious disease (mononucleosis, hepatitis, AIDS)?
20. _____ Is there any reason that would preclude you from engaging in physical activity?
21. _____ Do you participate in regular cardiorespiratory exercise?
22. _____ _____ State the average number of days and total time per week in cardiorespiratory exercise.

If you answered "yes" to one or more questions, you need to research activities with the primary investigator. Answering "yes" to any of the questions/statements may remove the subject from inclusion in this research.

I, ________________________________, hereby state that I have honestly completed all questions/statements. I recognize that my participation in this research is voluntary and that I may be removed from the study for any health risks or adverse responses to exercise treatments. Date: ___________

Witness: ____ Date:______________

(Thomas S Altena, Primary Investigator)

APPENDIX B

METABOLIC EQUATIONS AND CALCULATION FOR CALORIC EXPENDITURE

Running Metabolic Equation

$$m.min^{-1} \times 0.2 \frac{ml.kg^{-1}.min^{-1}}{m.min^{-1}} + Gr \times m.min^{-1} \times \frac{0.9\ ml.kg^{-1}.min^{-1}}{m.min^{-1}} + 3.5\ ml.kg^{-1}.min^{-1}$$

Walking Metabolic Equation

$$m.min^{-1} \times 0.1 \frac{ml.kg^{-1}.min^{-1}}{m.min^{-1}} + Gr \times m.min^{-1} \times \frac{1.8\ ml.kg^{-1}.min^{-1}}{m.min^{-1}} + 3.5\ ml.kg^{-1}.min^{-1}$$

Calculation for Caloric Expenditure

Relative VO_2 x Bodyweight in Kg. x 5 kcal•L•min^{-1} x Minutes of Exercise

APPENDIX C

BORG'S SCALE OF RATING OF PERCEIVED EXERTION

BORG'S SCALE OF RATING OF PERCEIVED EXERTION

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	

APPENDIX D

BRUCE TREADMILL PROTOCOL

BRUCE TREADMILL RESULTS

NAME:____ AGE:______

GENDER: M F

DATE:________________
MEDICATIONS:____________________________________

MPHR:__________ 85% MPHR__________

RESTING DATA
HR: (supine)_______ (standing)______ BP: (supine)_____/_____ (standing)
_____/______

EXERCISE DATA

Stage	*Minutes*	*Speed mph*	*% Grade*	*V02*	*METS*	*HR*	*BP*	*RPE*	*BLC*	*Comments*
1	*1-3*	*1.7*	*10*							
2	*4-6*	*2.5*	*12*							
3	*7-9*	*3.4*	*14*							
4	*10-12*	*4.2*	*16*							
5	*13-15*	*5.0*	*18*							
6	*16-18*	*5.5*	*20*							
7	*19-21*	*6.0*	*22*							

RECOVERY DATA

3 Min. (HR)__________ (BP) _____/_____

5 Min. (HR)__________ (BP) _____/______

8 Min. (HR)__________ (BP) _____/______

EKG COMMENTS DURING RECOVERY: WNL OTHER (Explain):

REASONS FOR STOPPING: General Fatigue; Anxiety; Dyspnea; Nausea; Dizziness; Angina; Claudication; Hypotension; Hypertension; Cyanosis; Ataxia; Confusion; Pallor; Cold, Clammy Skin; EKG changes; Poor Perfusion; Other(s) (Explain):

APPENDIX E

ADDITIONAL BIOCHEMICAL BACKGROUND ON LACTATE

Additional Biochemical Background on Lactate

Many researchers report that lactate is normally formed from pyruvate, which is derived from glucose when broken down for energy. The reaction occurs anaerobicly in the cells of higher organisms when the amount of oxygen is limited, as would be the case of intense exercise. This reaction is a result of the reduction of pyruvate by NADH, to form lactate. This biochemical reaction is catalyzed by the enzyme lactate dehydrogenase. The overall reaction in the conversion of glucose into lactate is:

Anaerobic Glycolysis

$$\text{Glucose} + 2\ \text{Pi} + 2\ \text{ADP} \quad 2\ \text{lactate} + 2\ \text{ATP} + 2\ H_2O.$$

Aerobic Glycolysis

$$\text{Glucose} + 2\text{Pi} + 2\text{ADP} + 2\text{NAD}^+ \quad 2\text{Pyruvate} + 2\text{ATP} + 2\text{NADH} + 2H^+ + 2H_2O$$

Continued glycolysis, the breakdown and conversion of stored glycogen into ATP, under anaerobic conditions, depends on the availability of NAD+. Furthermore, the accumulation of both NADH and pyruvate is reversed by the enzyme lactate dehydrogenase, which oxidizes NADH to NAD+ as it reduces pyruvate to lactate (Brooks et al., 2000; and Robergs et al., 1997). The enzyme lactate dehydrogenase (LDH) reduces pyruvate to lactate by the following equation:

$$\text{Pyruvate} + \text{NADH} + H^+ \quad \text{Lactate} + \text{NAD}^+.$$

APPENDIX F

RUNNING TREADMILL RESULTS DURING LACTATE THRESHOLD TEST

RUNNING TREADMILL RESULTS DURING LACTATE THRESHOLD TEST

NAME: ______________________ AGE: ________ GENDER: M F

DATE: ____/____/________ MEDICATIONS: ______________________

TEST: max or submax MPHR: ________

HR: (supine) _____(standing) _______ BP: (supine)____ /____ (standing)_____ /____

EXERCISE DATA: speed_____(mph) at LT

Stage	Speed (mph)	Minutes	BLC	RPE	HR	VO2	BP	METS
1	4.0	0-2:59					/	
2	4.4	3:00-5:59					/	
3	4.8	6:00-8:59					/	
4	5.2	9:00-11:59					/	
5	5.6	12:00-14:59					/	
6	6.0	15:00-17:59					/	
7	6.4	18:00-20:59					/	
8	6.8	21:00-23:59					/	
9	7.2	24:00-26:59					/	
10	7.6	27:00-29:59					/	
11	8.0	30:00-32:59					/	
12	8.2	33:00-35:59					/	
13	8.6	36:00-38:59					/	

RECOVERY DATA

3 Min. (HR) ____________ (BP) /____________

5 Min. (HR) ____________ (BP) /____________

8 Min. (HR) ____________ (BP) /____________

EKG COMMENTS DURING RECOVERY: WNL OTHER (Explain):

REASONS FOR STOPPING: General Fatigue; Anxiety; Dyspnea; Nausea; Dizziness; Angina; Claudication; Hypotension; Hypertension; Cyanosis; Ataxia; Confusion; Pallor; Cold, Clammy Skin; EKG changes; Poor Perfusion; Other(s) (Explain):

LAST STAGE/GRADE : ___________TOTAL TIME: ________MHR: _____________

MSBP: __________MDBP: ________ AEROBIC FITNESS CATEGORY: ______

APPENDIX G

IRB APPROVAL

Oklahoma State University
Institutional Review Board

Protocol Expires: 1/30/02

Date : Tuesday, February 13, 2001 IRB Application No ED0158

Proposal Title: A COMPARISON OF SELECTED PHYSIOLOGICAL VARIABLES IN RESPONSE TO TREADMILL ERGOMERTY AND ELLIPTICAL CROSSTRAINING EXERCISE, WHILE EXERCISING AT THE LACTATE THRESHOLD

Principal
Investigator(s) :

Thomas Altena
120 Colvin
Stillwater, OK 74078

Frank Kulling
104 Colvin
Stillwater, OK 74078

Reviewed and
Processed as: Full Board

Approval Status Recommended by Reviewer(s) : Approved

Signature :

Carol Olson, Director of University Research Compliance

Tuesday, February 13, 2001
Date

Approvals are valid for one calendar year, after which time a request for continuation must be submitted. Any modifications to the research project approved by the IRB must be submitted for approval with the advisor's signature. The IRB office MUST be notified in writing when a project is complete. Approved projects are subject to monitoring by the IRB. Expedited and exempt projects may be reviewed by the full Institutional Review Board.

APPENDIX H

350 KCAL ELLIPTICAL PROTOCOL WORKSHEET

350 kcal Elliptical Protocol Worksheet

ELLIPTICAL FITNESS CROSSTRAINER

Name: ______________________________

PVO_2max: ________ $ml{\bullet}kg{\bullet}min^{-1}$

Time of Day: _________

VO_2 Corresponding to the Lactate Threshold: ___________ $ml{\bullet}kg{\bullet}min^{-1}$

VO_2-drift allowed ___________ $ml{\bullet}kg{\bullet}min^{-1}$

EXERCISE DATA

Stage Time	**VO_2**	**Heart Rate**	**RPE**	**METS**	**O_2-pulse**	**METS on EFX**

APPENDIX I

350 KCAL TREADMILL PROTOCOL WORKSHEET

350 kcal Treadmill Protocol Worksheet

TREADMILL

Name: ________________________________

PVO_{2max}: ________ ml•kg•min^{-1}

Time of Day: _________

VO_2 Corresponding to the Lactate Threshold: ___________ ml•kg•min^{-1}

EXERCISE DATA

Stage Time	VO_2	Heart rate	RPE	METS	O_2-pulse

VITA

Thomas S Altena

Candidate for the Degree of

Doctor of Education

Thesis: A COMPARISON OF SELECTED PHYSIOLOGICAL VARIABLES IN RESPONSE TO TREADMILL ERGOMETRY AND ELLIPTICAL CROSSTRAINING EXERCISE, WHILE EXERCISING AT THE LACTATE THRESHOLD

Major Field: Applied Educational Studies

Biographical:

Personal Data: Born in Ida Grove, Iowa on August 16, 1973 and was adopted by parents Dr. Syne D. and Judith A. Altena

Education: Graduated with Bachelor of Arts degree with a major in Physical Education and minor in Health Education from Dordt College in May 1996. Graduated with Master of Arts degree from the University of South Dakota with an emphasis in Exercise Science in May 1998. Completed the requirements for the Doctor of Education degree with in the program of Health and Human Performance from Oklahoma State University in August 2001.

Experience: Currently is a faculty member in the Exercise Physiology Program at the University of Missouri-Columbia as a Research Assistant Professor. Graduate Associate at Oklahoma State University and Graduate Teaching Assistant at the University of South Dakota.

Professional Memberships: American College of Sports Medicine (Certified Health-Fitness Instructor), the American Alliance for Health, Physical Education, Recreation and Dance, and the Texas Alliance for Health, Physical Education, Recreation and Dance.