Physiological and Perceptual Responses to Elliptical Trainer Exercise at Three Different Grade and Resistance Settings

Wehmeyer

Follow this and additional works at: https://scholarworks.wmich.edu/masters_theses

Part of the Health and Physical Education Commons

Recommended Citation
PHYSIOLOGICAL AND PERCEPTUAL RESPONSES TO ELLIPTICAL TRAINER EXERCISE AT THREE DIFFERENT GRADE AND RESISTANCE SETTINGS

by

Katherine A. Wehmeyer

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Arts
Department of Health, Physical Education, and Recreation

Western Michigan University
Kalamazoo, Michigan
August 2001
ACKNOWLEDGMENTS

Although my two years attending Western Michigan University have been challenging, frustrating, and, this year, heartbreaking, they have also been rewarding, educational, and empowering. By completing this thesis and earning my Master’s Degree, I will have accomplished one of my life goals. These accomplishments could not have been possible without the help of many individuals, and I would like to take this opportunity to thank them. First, I extend my deepest and sincerest gratitude to Dr. Mary Dawson and Dr. Roger Zabik. Thank you for your expertise, patience, encouragement, and, mostly, your confidence in my abilities. Dr. Timothy Michael and Dr. Daniel Carl, the other members of my thesis committee, also deserve recognition. Thank you both for your assistance with this project. I’d like to thank Teal Peabody, M.A., and the graduate assistants who helped in the lab with the many hours of data collection. Lastly, thanks to my family and friends for your never-ending support and love—I’ll be home soon!

Katherine A. Wehmeyer
PHYSIOLOGICAL AND PERCEPTUAL RESPONSES TO ELLIPTICAL TRAINER EXERCISE AT THREE DIFFERENT GRADE AND RESISTANCE SETTINGS

Katherine A. Wehmeyer, M. A.
Western Michigan University, 2001

The study compared the effects of elliptical trainer exercise at different grade (G) and resistance (R) settings on the following variables: (a) heart rate, (b) heart rate as a percentage of maximum heart rate, (c) relative VO₂, (d) relative VO₂ as a percentage of VO₂ max, (e) absolute energy cost, (f) relative energy cost, (g) RPE for legs, (h) RPE for chest, and (i) RPE for overall body. Heart rate, relative VO₂, Respiratory Exchange Ratio, and RPE were measured as 30 subjects completed nine experimental conditions. The experimental conditions consisted of striding forward on the elliptical trainer (Precor® EFX™ 546) at 130 strides per min at three grades—G4, G8, and G12, at three resistances—R4, R8, and R12. ANOVAs revealed physiological variables and RPE for legs increased significantly as grade and resistance were increased. ANOVAs revealed RPEs for chest and overall body increased significantly as resistance was increased. Increased resistance caused greater physiological and perceptual responses than increased grade. The elliptical trainer provided a range of workloads and would be an appropriate cardiovascular exercise modality for adults of varying fitness levels.
# TABLE OF CONTENTS

ACKNOWLEDGMENTS ................................................................................................................... ii

LIST OF TABLES ........................................................................................................................... vii

CHAPTER

I. INTRODUCTION .................................................................................................................. 1
   Purpose of the Study .................................................................................................................. 2
   Statement of the Problem ......................................................................................................... 3
   Delimitations ............................................................................................................................. 3
   Limitations ............................................................................................................................... 4
   Assumptions ............................................................................................................................. 5
   Research Hypotheses ............................................................................................................... 5
   Definitions ............................................................................................................................... 6

II. LITERATURE REVIEW ......................................................................................................... 8
   Cardiovascular Exercise Guidelines ......................................................................................... 8
   Physiological Responses to Cardiovascular Exercise ............................................................ 9
   Perceptual Responses to Cardiovascular Exercise ............................................................... 10
   Indirect Calorimetry ............................................................................................................... 11
   Cardiovascular Machine Research ......................................................................................... 12
   Elliptical Trainer Research .................................................................................................... 14
   Variable Manipulations ......................................................................................................... 14
Table of Contents—Continued

CHAPTER

Various Elliptical Models .............................................................. 16

Comparative Effects .................................................................... 17

Summary .......................................................................................... 19

III. METHODS AND PROCEDURES .................................................. 21

Selection of Subjects ..................................................................... 21

Instrumentation ............................................................................. 22

Design of the Study ....................................................................... 22

Testing Procedures ...................................................................... 23

Maximal Treadmill Test ................................................................ 23

Elliptical Trainer Test .................................................................. 24

Treatment of Data ....................................................................... 25

IV. RESULTS AND DISCUSSION ....................................................... 27

Results ......................................................................................... 27

Subject Demographics .................................................................. 27

Heart Rate ..................................................................................... 28

HR as a Percentage of Maximum HR ......................................... 29

Relative VO₂ ............................................................................... 31

Relative VO₂ as a Percentage of VO₂ Max ................................... 33

Absolute Energy Cost .................................................................. 34
Table of Contents—Continued

CHAPTER

Relative Energy Cost.......................................................... 36
RPE for Legs....................................................................... 38
RPE for Chest ..................................................................... 40
RPE for Overall Body........................................................... 41
Discussion............................................................................ 43
Heart Rate............................................................................ 43
HR as a Percentage of Maximum HR.................................... 44
Relative VO_{2}................................................................. 46
Relative VO_{2} as a Percentage of VO_{2} Max......................... 48
Absolute and Relative Energy Cost........................................ 50
RPE for Legs, Chest, and Overall Body................................. 52
Summary............................................................................ 54

V. SUMMARY, FINDINGS, CONCLUSIONS, AND
RECOMMENDATIONS......................................................... 56

Summary ............................................................................ 56
Findings............................................................................. 57
Conclusions....................................................................... 61
Recommendations............................................................... 62

APPENDICES

A. Recruitment Script.......................................................... 63
APPENDICES

B. Health Screening Form ................................................. 65

C. Human Subjects Institutional Review Board
   Letter of Approval ...................................................... 69

D. Consent Form .......................................................... 71

E. Bruce Protocol .......................................................... 75

BIBLIOGRAPHY ............................................................. 77
<table>
<thead>
<tr>
<th>Table Number</th>
<th>Table Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ANOVA Summary for Heart Rate</td>
<td>29</td>
</tr>
<tr>
<td>2</td>
<td>ANOVA Summary for Heart Rate as a Percentage of Maximum Heart Rate</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>ANOVA Summary for Relative VO\textsubscript{2}</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>ANOVA Summary for VO\textsubscript{2} as a Percentage of Maximum VO\textsubscript{2}</td>
<td>34</td>
</tr>
<tr>
<td>5</td>
<td>ANOVA Summary for Relative Energy Cost (kcal · min\textsuperscript{-1})</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>ANOVA Summary for Relative Energy Cost (kcal · kg\textsuperscript{-1} · min\textsuperscript{-1})</td>
<td>37</td>
</tr>
<tr>
<td>7</td>
<td>ANOVA Summary for RPE for Legs</td>
<td>39</td>
</tr>
<tr>
<td>8</td>
<td>ANOVA Summary for RPE for Chest</td>
<td>41</td>
</tr>
<tr>
<td>9</td>
<td>ANOVA Summary for RPE for Overall Body</td>
<td>42</td>
</tr>
</tbody>
</table>
CHAPTER I

INTRODUCTION

Exercise equipment companies are continually developing new machines to keep up with demand for safe, effective, and innovative products to help improve or maintain cardiovascular fitness. One of the latest and most popular is a category of machines collectively known as elliptical trainers. Elliptical trainers are named for the oval-shaped path of motion the lower body follows during use of the machine. Users of these machines, fitness experts, and exercise equipment companies praise elliptical trainers for their low-impact workout, ease-of-use, and high level of comfort. Although elliptical trainers have been available for home and commercial use for several years, limited research is available regarding the effectiveness of these machines.

The first elliptical trainer was introduced by Precor® USA in 1995 (Florez, 1998). Currently, Precor® manufactures and distributes the most frequently used elliptical trainers in adult fitness centers (Precor® USA, 1998). The Precor® EFX™ 546, the elliptical trainer used in this study, has four variables the user can manipulate to change the intensity and focus of the exercise: (1) stride frequency, (2) direction of movement, (3) grade, and (4) pedal resistance.

Stride frequency or rate is determined by how fast the user is moving the foot pedals. The machine measures each pedal revolution as a stride, and strides per
minute (spm) is displayed for the user on the computerized control panel.

Directional movement of the foot pedals is determined by the user and can be forward or backward. The grade is the elevation of the ramp on which the foot pedals glide. When the grade is low, the path of motion of the foot pedals is similar to a horizontal ellipse. When the grade is high, the path of motion of the foot pedals is similar to a diagonal ellipse. The resistance relates to the force needed to move the foot pedals forward or backward.

On the Precor® EFXT M546, grade can be set at levels 1–20, 1 being the lowest grade (10°) and 20 being the highest grade (40°) (Precor® USA, 1998). Resistance can also be set from levels 1–20, 1 providing the least resistance and 20 providing the most resistance. The work output and relative energy cost associated with these numbers have not been determined. In addition, the effects of the elliptical trainer’s various grades and resistance levels have on physiological parameters and perceived exertion have yet to be extensively investigated. It has also been observed that many individuals using the machine in a college recreation center set the grade medium-high to very high, set the resistance very low, and stride at an extremely fast pace. This raises questions as to the effectiveness of those settings in regards to work output and energy cost.

Purpose of the Study

Elliptical trainers have been available on the exercise equipment market for several years. Despite the popularity of these machines, relatively little research has
been conducted examining this mode of aerobic exercise. The grade and resistance settings specific to the Precor® EFX™ 546 elliptical trainer and the machine's overall effectiveness need to be more quantitatively evaluated.

With increased knowledge of the physiological and perceptual responses at the different grade and resistance settings, users can select the most appropriate settings to meet their workout goals. Additionally, with this information, graded exercise test protocols can be designed utilizing the elliptical trainer. Since this mode of exercise is low impact, it is an ideal alternative for individuals with musculo-skeletal conditions who cannot perform high-impact exercise.

Statement of the Problem

This study compared physiological and perceptual responses to exercise on the Precor® EFX™ 546 elliptical trainer at three different grades and three different resistance settings. Physiological variables measured included heart rate (HR), HR as a percentage of maximum HR, relative oxygen consumption (VO₂), relative VO₂ as a percentage of VO₂ max, absolute energy cost (kcal · min⁻¹), and relative energy cost (kcal · kg⁻¹ · min⁻¹). To measure perceptual responses, rate of perceived exertion (RPE) was assessed for the legs, chest, and overall body during exercise.

Delimitations

The following delimitations were identified for this study:
1. Subjects were volunteer students or employees from Western Michigan University, were between the ages of 18 and 31 years, were classified as “low risk” (American College of Sports Medicine, 2000), and were free of musculo-skeletal problems.

2. Subjects exercised regularly 2 to 3 times per week.

3. Subjects performed one exercise trial at three grades (4, 8, and 12) at three resistances (4, 8, 12), a total of 9 conditions.

4. The stride rate was 130 spm for each experimental condition.

5. The direction of movement was forward for each experimental condition.

6. Subjects used the Precor® EFX™ 546 elliptical trainer.

7. The study was performed in a laboratory setting.

Limitations

The following were limitations of the study:

1. Subjects were volunteers and were not randomly selected; therefore, this research may not represent the general population.

2. Subjects performed three conditions in one session and fatigue may have affected the results.

3. Subjects performed only one trial for each of the experimental conditions. Additional trials may have produced more reliable results.
Assumptions

The following assumptions were made in this study:

1. Subjects performed to the best of their abilities.

2. Subjects were adequately warmed up at the time the trials were performed.

3. Subjects understood the RPE chart and expressed their level of exertion accurately and consistently during the study.

4. Subjects sufficiently recovered between trials.

Research Hypotheses

The study tested these hypotheses:

1. Heart rate, heart rate as a percentage of heart rate max, relative VO₂, relative VO₂ as a percentage of VO₂ max, relative energy cost, and absolute energy cost will be highest at grade 12 and lowest at grade 4.

2. Heart rate, heart rate as a percentage of heart rate max, relative VO₂, relative VO₂ as a percentage of VO₂ max, absolute energy cost, and relative energy cost will be highest at resistance 12 and lowest at resistance 4.

3. RPE for the legs, chest, and overall body will be highest at grade 12 and lowest at grade 4.

4. RPE for the legs, chest, and overall body will be highest at resistance 12 and lowest at resistance 4.
Definitions

The following terms were defined for the study:

1. **Absolute energy cost** (kcal · min⁻¹): The amount of energy measured in kilocalories (kcal) required per minute to perform a physical activity.

2. **Elliptical trainer**: A cardiovascular exercise machine in which the path of motion of the foot pedals is in the shape of an ellipse and resistance and grade levels can be manipulated.

3. **Maximal oxygen consumption** (VO₂ max): The maximal amount of oxygen that can be consumed by the body during exercise (Brooks, Fahey, & White, 1996).

4. **Oxygen consumption** (VO₂): The amount of oxygen that is used by the body during physical activity (Brooks et al., 1996).

5. **Peak oxygen consumption** (VO₂ peak): An oxygen consumption measurement made during maximal exercise that does not fit the criteria for VO₂ max (Brooks et al., 1996).

6. **Rate of perceived exertion** (RPE): A rating scale from 6 (no exertion) to 20 (maximal exertion), which can be used to determine relative exercise intensity (Brooks et al., 1996).

7. **Relative energy cost** (kcal · kg⁻¹ · min⁻¹): The amount of energy per kilogram of body weight per minute that is required to perform a physical activity.
8. *Relative oxygen consumption* (relative VO₂): Oxygen consumption measured per minute relative to body mass (ml · kg⁻¹ · min⁻¹).

9. *Respiratory exchange ratio* (*R* value): The ratio of carbon dioxide produced to oxygen consumed during exercise (VCO₂ · VO₂⁻¹). *R* values are representative of substrate utilization during steady state exercise; a value of 1.0 represents 100% carbohydrate metabolism and 0.7 represents 100% fat metabolism (Robergs & Roberts, 1997).

10. *Stride rate or frequency*: The total number of revolutions per minute of both foot pedals on the elliptical trainer. Stride rate is measured in strides per minute (spm).
CHAPTER II
LITERATURE REVIEW

Indoor exercise machines are used by many individuals to improve aerobic fitness and for weight management. Several types of cardiovascular machines are currently available. Elliptical trainers are relatively new machines. Since their introduction to the fitness market in the mid 1990s, they have become increasingly popular. Due to the recent introduction of elliptical trainers, there are few studies examining physiological and perceptual responses to the elliptical trainer and its various grade and resistance settings. This chapter contains the following sections: (a) cardiovascular exercise guidelines, (b) physiological response to cardiovascular exercise, (c) perceptual response to cardiovascular exercise, (d) indirect calorimetry, (e) cardiovascular machine research, (f) elliptical trainer research, and (g) summary.

Cardiovascular Exercise Guidelines

Performing physical activity and improving cardiovascular fitness has been associated with many health benefits including reduced risk of coronary artery disease, stroke, some cancers, diabetes, and other diseases (American College of Sports Medicine, 2000). As a result, the Centers for Disease Control and the American College of Sports Medicine (ACSM) recommend that American adults should accumulate a minimum of 30 min of moderate intensity physical activity on
most or all days of the week (American College of Sports Medicine, 2000). Indoor exercise machines are a common and effective way of meeting daily physical activity needs.

The ACSM has recommended guidelines to follow to improve cardiovascular fitness. Cardiovascular or aerobic exercise is any activity that uses large muscle groups and is rhythmical and continuous (e.g., running, walking, swimming, cycling, aerobic dance, stair stepping, and the like). These types of activities should be done 3 to 5 days per week for 20 to 60 min per session. The workout intensity should be 55 to 90% of maximum heart rate, 40 to 85% of heart rate reserve, or 50 to 85% of VO₂ max. Ideally, 150 to 400 kcal should be expended through physical activity per day. As an individual’s fitness level improves, it is necessary to work toward the higher ends of the recommended guidelines to maintain or continue to improve cardiovascular fitness. Previously sedentary individuals should begin at the lower ends of the ranges and gradually increase workout intensity, frequency, and duration as appropriate (American College of Sports Medicine, 2000).

Physiological Responses to Cardiovascular Exercise

Performing cardiovascular activities increases the body’s need for energy and therefore oxygen. As a result, during aerobic exercise, heart rate, respiratory rate, and VO₂ increase. The magnitude of the response is based on the individual’s fitness level and the intensity, duration, and type of activity. With long-term training, the
body becomes more efficient at consuming and utilizing O₂ and providing energy to its working muscles. The following are some of the adaptations to aerobic exercise training: (a) increased VO₂ max, (b) decreased resting heart rate, (c) increased concentration of aerobic metabolic enzymes, (d) increased concentration of red blood cells, (e) decreased blood pressure, and (f) improved blood lipid and cholesterol profile (American College of Sports Medicine, 2000).

Perceptual Responses to Cardiovascular Exercise

Perceived exertion is how hard an individual thinks and feels he or she is exercising. This rating or perceived exertion (RPE) is subjective and is based on the level of effort or discomfort that is felt during an exercise bout. A commonly used RPE scale is Borg’s original scale and ranges from 6 to 20 with the different numbers corresponding to levels of work. For example, if one is working at a 7, then he or she perceives the exercise as very, very light. On the other end of the scale, if one is working at a 19, then he or she perceive the exercise as very, very hard. During cardiovascular exercise, it is recommended that an individual’s RPE be 12 to 16, which corresponds to somewhat hard to hard (American College of Sports Medicine, 2000).

RPE should be used in conjunction with heart rate when determining exercise intensity. Different types of cardiovascular exercise can elicit similar physiological responses but be perceived differently (American College of Sports Medicine, 2000).
Indirect Calorimetry

Knowing the energy expenditure of an activity is useful when planning exercise prescriptions for weight loss and weight management. Direct calorimetry is the gold standard for measuring energy expenditure and involves measuring the amount of heat produced by a body at rest or during exercise. The special equipment and methodology used in direct calorimetry, however, make it an impractical method of measuring energy expenditure in many situations. As a result, indirect calorimetry is commonly used. In this method, energy expenditure is determined by measuring O₂ consumption (VO₂). This is possible because there is a direct relationship between O₂ consumption and heat production (Powers & Howley, 2001).

Open circuit spirometry is the most common technique used to measure O₂ consumption. Metabolic carts consisting of various gas chambers and computer technology are able to measure the volume of air inspired, the volume of air expired, and the fraction of O₂ and CO₂ present in the expired air. With that information, the computer can calculate the volume of O₂ consumed and the volume of CO₂ produced. Prior to gas collection, the metabolic cart must be calibrated with a known concentration of O₂ and CO₂. Depending on the technology used, expired air can be analyzed over a specific amount of time (i.e., averaged every 20 or 30 sec) or reported breath-by-breath (Robergs & Roberts, 1997).
The ratio of CO₂ produced to O₂ consumed is called the respiratory exchange ratio (R or RER). R is an estimation of the respiratory quotient (RQ). RQ refers to respiration at the cellular level and indicates the foodstuffs being catabolized. R is measured from external respiration—the ventilated air in the lungs. For many exercise conditions, it is assumed that R is equal to RQ (Robergs & Roberts, 1997).

The energy released for every liter of O₂ consumed at different RQ values are known; therefore, it is possible to calculate energy expenditure during exercise. Nonprotein R tables range from 0.71 to 1.0. An R of 0.71 indicates theoretically that pure fat is being catabolized, which yields 4.7 kcal · LO₂⁻¹ · min⁻¹. An R of 1.0 indicates theoretically that pure carbohydrates are being catabolized, which yields 5.05 kcal · LO₂⁻¹ · min⁻¹ (Powers & Howley, 2001).

Cardiovascular Machine Research

Several varieties of indoor exercise machines are available to help improve aerobic fitness and manage body weight. This section reviews studies examining the physiological effects of these machines. The studies compare physiological and perceptual responses between exercise on cardiovascular machines at similar intensities, RPE levels, and length of the exercise bout.

Thomas, Feiock, and Araujo (1989) compared the metabolic responses of prolonged exercise on four exercise machines: (1) stationary cycle, (2) rowing machine, (3) cross-country ski simulator, and (4) treadmill. Subjects exercised on
each machine for 60 min at 65% of their maximum HR. Steady state VO₂ and RER were measured during the exercise bouts. Total energy expenditure and fat energy expenditure were calculated using indirect calorimetry. Steady state VO₂ values ranged from 2.167 L · min⁻¹ (rowing machine) to 2.427 L · min⁻¹ (stationary cycle) and were not significantly different. Total energy expenditure was also not significantly different between the machines and ranged from 208 kcal (rowing machine) to 284 kcal (treadmill). Fat energy expenditure was somewhat higher and was a larger percentage of total energy expenditure for the cross-country ski simulator and treadmill, but the difference was not statistically significant. The research conclusion was the metabolic responses to the four exercise modes were similar when working at the same relative intensity. Therefore, when designing exercise prescriptions for clients, it is acceptable to allow them to choose which type of cardiovascular machine to use since one mode is not superior to another.

Zeni, Hoffman, and Clifford (1996) compared energy expenditure at given RPE levels on six indoor exercise machines: (1) Airdyne stationery cycle, (2) cross-country ski simulator, (3) cycle ergometer, (4) rowing machine, (5) stair stepper, and (6) treadmill. The subjects exercised on each machine at three self-selected intensity levels for a total of 15 min (5 min at each level). The three levels corresponded to RPE's of 11 (fairly light), 13 (somewhat hard), and 15 (hard). During the final minute of each stage, heart rates were averaged and expired air was collected and analyzed. Energy expenditure was determined using indirect calorimetry. Immediately after the exercise bout, blood lactate levels were collected.
The results showed the rates of energy expenditure at the same RPE level on different machines varied by 261 kcal · hr\(^{-1}\). The treadmill induced greater energy expenditure at the given RPE values than all of the other exercise machines. The ski simulator, rowing machine, and stair stepper induced greater energy expenditures than the Airdyne and cycle ergometer. Heart rate was significantly different between the six exercise modes with the treadmill and stair stepper eliciting the highest values. Lactate concentration varied significantly with the greatest concentration being associated with the rowing machine and the stair stepper. The research conclusion was that the treadmill is the optimal indoor exercise machine for energy expenditure at a given RPE.

**Elliptical Trainer Research**

**Variable Manipulations**

Kravitz, Wax, Mayo, Daniels, and Charette (1998) examined physiological and perceptual responses between different grades, resistances, speeds, and directions on an elliptical trainer (Precor® EFX\(^{TM}\)). The study measured relative VO₂, ventilation (VE), HR, caloric expenditure, and RPE over five exercise conditions: (1) forward striding (FWD), (2) backward striding (BWD), (3) forward striding with increased resistance (FR), (4) forward striding with increased speed (SP), and (5) forward striding with increased grade (GR). For most conditions, the grade was set at level 5 out of 10 levels. For the GR condition, the grade was set at
level 8. The researchers did not disclose the resistance level at which the machine was set during any of the experimental conditions. Stride frequency was 125 spm for all conditions, except for the SP condition in which it was 135 spm. The investigators indicated that the FR and SP conditions elicited significantly greater physiological responses than the other three conditions. BWD and GR elicited similar responses and were both greater than the FWD condition. Average relative VO$_2$ ranged from 22.3±3.0 ml·kg$^{-1}$·min$^{-1}$ for FWD to 29.6±4.6 ml·kg$^{-1}$·min$^{-1}$ for FR. Average HR ranged from 145.3±16.7 bpm for FWD to 166.9±19.1 bpm for FR. Average caloric expenditure ranged from 8.1±1.6 kcal·min$^{-1}$ for FWD to 10.7±1.7 kcal·min$^{-1}$ for FR. Average RPE ranged from 10.9±1.2 for FWD to 13.4±2.0 for FR. The study indicated that increased resistance had more of an effect than increased grade.

In another study, Bakken (1997) examined physiological and perceptual differences between forward (FWD) and backward (BWD) striding on an elliptical trainer (Precor® C544 Transport) at 100 spm and 120 spm. Subjects exercised at each experimental condition until steady states were reached (5 to 6 min). The resistance level was set at 5 out of 10 levels, and the grade was set at 10 out of 10 levels. At 100 spm, there were significant differences between HR and RPE responses to FWD and BWD striding. The mean values for HR and RPE for FWD and BWD striding were 141.1 and 145.1 bpm, respectively, and 10.5 and 11.1, respectively. Other physiological responses were not significantly different at 100 spm. Mean values for FWD for VE, relative VO$_2$, absolute VO$_2$, RER, and kcal
expenditure were $36.3 \text{ L} \cdot \text{min}^{-1}$, $22.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, $1.27 \text{ L} \cdot \text{min}^{-1}$, 0.95, and 6.4 kcal \cdot \text{min}^{-1}, respectively. Values for BWD were $37.5 \text{ L} \cdot \text{min}^{-1}$, $22.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, $1.26 \text{ L} \cdot \text{min}^{-1}$, 0.97, and 6.3 kcal \cdot \text{min}^{-1}, respectively.

At 120 spm, there were no significant differences between FWD and BWD. Mean values for VE, relative VO\textsubscript{2}, absolute VO\textsubscript{2}, HR, RER, and kcal expenditure, and RPE for FWD were $43.8 \text{ L} \cdot \text{min}^{-1}$, $26.8 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, $1.51 \text{ L} \cdot \text{min}^{-1}$, 158.2 bpm, 0.97, and 7.8 kcal \cdot \text{min}^{-1}, and 12.9, respectively. Mean values for BWD were $45.5 \text{ L} \cdot \text{min}^{-1}$, $26.4 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, $1.52 \text{ L} \cdot \text{min}^{-1}$, 161.7 bpm, 0.97, and 7.7 kcal \cdot \text{min}^{-1}, and 13.4, respectively. Striding at 120 spm elicited significantly greater physiological and perceptual responses than striding at 100 spm.

Unlike Kravitz et al. (1998), Bakken (1997) found little physiological and perceptual differences between FWD and BWD conditions. Similar in their findings, however, was that faster striding rates increased metabolic responses and RPE.

**Various Elliptical Models**

Cotton (1998) compared physiological responses of four different elliptical trainers marketed to the home consumer (Ellipse, Cyclone, PowerTrain, and Health Rider). The machines elicited similar responses in HR (139.3±23.6 bpm to 144.5±21.0 bpm), percentage of maximum HR (71% to 73%), caloric expenditure (7.8±1.0 kcal \cdot \text{min}^{-1} to 8.3±0.8 kcal \cdot \text{min}^{-1}), and RPE (12.5±1.9 to 13.0±1.7).
Comparative Effects

A reoccurring theme of available elliptical trainer research was comparing the physiological responses of elliptical machines to other common exercise machines. Porcari, Zedaker, Naser, and Miller (1998) compared physiological responses of elliptical trainer exercise (NordicTrack Ellipse) to treadmill walking and running, stationary cycling, and stair stepping. Subjects exercised 20 min at a self-selected pace on each machine on separate days. HR, relative VO$_2$, caloric expenditure, and RPE were monitored during each exercise session. The study found HR, relative VO$_2$, and caloric expenditure were similar for the elliptical trainer (31.5 ml · kg$^{-1}$· min$^{-1}$, 161 bpm, and 11.5 kcal ·min$^{-1}$) and treadmill running (32.9 ml · kg$^{-1}$· min$^{-1}$, 157 bpm, and 11.9 kcal ·min$^{-1}$). These two exercise modes also produced significantly greater physiological effects than all of the other machines. Despite the differences in physiological exercise response, RPE was similar for all machines, ranging from 11.7 for treadmill walking to 12.8 for treadmill running. The average RPE for the elliptical trainer was 12.7. The study also compared ground reaction forces between the exercise modalities and found the elliptical trainer had less than half the impact forces of treadmill running. Researchers concluded the elliptical machine may be a safer alternative to running due to its low ground reaction forces.

In another comparative study, Wiley, Mercer, Chen, and Bates (1999) found no difference between peak VO$_2$ and peak HR elicited during graded exercise tests
on an elliptical trainer (Precor® Inc.) (52±11 ml·kg⁻¹·min⁻¹ and 191±2 bpm) and a treadmill (53±8 ml·kg⁻¹·min⁻¹ and 193±10 bpm). Also, time to exhaustion was similar between the two machines. The study concluded elliptical trainer exercise might be a suitable alternative to running.

Pecchia, Evans, Edwards, and Bell (1999) compared physiological responses between exercise on an elliptical trainer (Precor® Transport) and a treadmill at similar VO₂ values. Subjects exercised at 55% of VO₂ max for 20 min. No significant differences were found in relative VO₂, HR, or RPE for the elliptical trainer (22.7±29 ml·kg⁻¹·min⁻¹, 130.4±16.1 bpm, and 12.5±2.0) and the treadmill (23.9±3.5 ml·kg⁻¹·min⁻¹, 120.8±13.1 bpm, and 11.5). Researchers concluded the elliptical trainer is a valid mode of cardiovascular exercise.

Clay (2000) used the elliptical trainer in a different type of study. She compared the actual caloric expenditure measured via indirect calorimetry methods with the caloric expenditure estimated by the computer in the cardiovascular machine console. Three machines were used in the study: (1) elliptical trainer, (2) stair climber, and (3) treadmill. Subjects exercised for 10 min at 75% of HR max. Specific elliptical grades, resistance setting, and striding rate were not disclosed. Likewise, there was no mention of treadmill speed or stair climber stepping rate. For all exercise modalities, the computer in the machines overestimated caloric expenditure. For the elliptical trainer (70.83 kcal·min⁻¹ actual vs. 73.06 kcal·min⁻¹ machine) and treadmill (63.28 kcal·min⁻¹ actual vs. 67.67 kcal·min⁻¹ machine), the
overestimations were not statistically significant. However, the difference between the stair climber actual and machine estimation caloric expenditure was significant (49.68 kcal · min⁻¹ actual vs. 69.11 kcal · min⁻¹ machine).

Summary

Knowledge of the importance of acquiring daily physical activity for optimal health is becoming pervasive. As a result, exercise equipment companies manufacture a variety of indoor cardiovascular machines to help individuals with their activity needs. The elliptical trainer, a relatively new device, is one of the many machines available on the fitness equipment market.

In general, physiological responses to elliptical trainer exercise are similar to or greater than other indoor exercise machines. In the research presented, the elliptical trainer appears to be an effective mode of cardiovascular exercise. In addition, advantages of the elliptical trainer over other forms of cardiovascular exercise may be its low stress on joints due to low ground reaction forces and user’s low RPE during the machine’s use.

Limitations exist in this body of elliptical trainer research. Many different brands and models of elliptical trainers were used in the studies, and most of the research did not discuss the specifics regarding grade or resistance settings of the machines or striding frequency. Therefore, it is difficult to make direct comparisons between the studies. Additional quantitative research is needed to further evaluate the
effectiveness of elliptical trainers and the physiological and perceptual responses to the machine’s various grade and resistance settings.
CHAPTER III

METHODS AND PROCEDURES

The purpose of this study was to measure and compare the physiological and perceptual responses to exercise on an elliptical trainer at three different grades and three different resistance levels during forward striding. The physiological variables measured were: (a) HR, (b) HR as a percentage of maximum HR, (c) relative VO₂, (d) relative VO₂ as a percentage of VO₂ max, (e) absolute energy cost, and (f) relative energy cost. Perceptual responses assessed included RPE for the legs, chest, and overall body. VO₂ max and maximum HR were measured in order to determine relative VO₂ and HR as a percentage of their maximum values during each exercise condition, respectively. This chapter contains the following topics: (a) selection of subjects, (b) instrumentation, (c) design of the study, (d) testing procedures, and (e) treatment of data.

Selection of Subjects

Subjects in the study were students and employees from Western Michigan University, Kalamazoo, aged 18–31 years. Subjects were recruited from Health, Physical Education, and Recreation classes and the Student Recreation Center (see Recruitment Script, Appendix A). Each subject was required to complete a health screening form (Howley & Franks, 1997) (see Health Screening Form, Appendix 21
B). Only those subjects considered “low risk” by ACSM guidelines were selected to participate. Subjects were free of musculo-skeletal problems and had actively exercised 2–3 days per week at the time of the study. The Human Subjects Institutional Review Board of Western Michigan University gave approval to conduct the study (see Approval Form, Appendix C). Prior to testing, each subject signed and dated a consent form (see Consent Form, Appendix D).

Instrumentation

Open-circuit spirometry was used during the maximal treadmill and elliptical testing to measure VO₂. The equipment used for the testing was a Sensormedics metabolic cart, model Vmax 229 LV Lite, Yorba Linda, CA. A four-lead electrocardiogram (EKG), Cardio-soft, GE Marquette Medical Systems, Milwaukee, WI was used to measure heart rate during both the maximal treadmill and elliptical testing. Borg’s original RPE scale was used as an indicator of the subjects’ tolerance to exercise and exhaustion level (American College of Sports Medicine, 2000). A treadmill, Quinton Instruments model 643, Seattle, WA was used during the maximal treadmill testing. During the exercise conditions, subjects exercised on an elliptical trainer, model EFX™ 546, Precor® Inc., Bothel, WA.

Design of the Study

The purpose of this study was to measure and compare physiological and perceptual responses during forward striding on the Precor® elliptical trainer at
three grades and three resistances. The study constituted a repeated measures
design. In each testing session, subjects exercised at a constant grade at three
different resistance workloads. The workloads (grade × resistance) were presented
in a random order. The three grade (G) settings studied were: (1) 4, (2) 8, and (3)
12. The three resistance (R) settings were: (1) 4, (2) 8, and (3) 12. The dependent
variables for this study were: (a) HR, (b) HR as a percentage of maximum HR, (c)
relative VO₂, (d) relative VO₂ as a percentage of VO₂ max, (e) absolute energy
cost, (f) relative energy cost, (g) RPE for legs, (h) RPE for chest, and (i) RPE for
overall body.

Testing Procedures

Maximal Treadmill Test

All testing took place in the Exercise Physiology Laboratory in the Student
Recreation Center at Western Michigan University, Kalamazoo. Subjects performed
two VO₂ max tests on different days. The subjects warmed up by walking on the
treadmill for 3 min at 1.7 mph at 0% grade. During the VO₂ max test, the treadmill
speed and grade increased every 3 min (see Bruce Protocol, Appendix E). Subjects’
HR, EKG, and relative VO₂ were measured continuously during the test. Two
minutes into each stage, blood pressure was measured and subjects were asked to
assess their overall RPE. The test continued until the subjects reached volitional
fatigue. Two max tests were completed to insure an accurate VO₂ max
measurement. The higher VO₂ peak value of the two treadmill tests was used in the data analysis. Subjects’ VO₂ peak were assumed to be an estimation of their VO₂ max.

Elliptical Trainer Test

Prior to the elliptical trainer testing sessions, each subject warmed up for 10–15 min using his or her own personal protocol. After warming up, subjects exercised on the elliptical trainer at the randomly determined grade and resistance levels.

Subjects completed the experimental testing in three sessions on separate days. During each session, subjects completed one of the following conditions: (a) G4, (b) G8, or (c) G12. During each grade condition, the three resistance levels were presented in random order: (1) R4, (2) R8, and (3) R12. Subjects were required to stand with their feet at the front of the pedals and place their palms on the handlebars for balance only. Subjects were not allowed to grasp the handles with their fingers. Stride rate was controlled with the use of a metronome set at 65 beats per minute (bpm). Each beat of the metronome corresponded with one revolution of either the right or left foot. Subjects were able to select which foot was synchronized with the metronome. Sixty-five bpm was the equivalent of 130 spm.

The subjects exercised at the predetermined grade, resistance level, and cadence for 5 min. A steady state was reached approximately 3 min into the exercise session. Steady state was determined when the HR measurements at the 3rd and 4th min were within 5 beats of each other. When steady state was achieved, HR, relative
VO₂, and R value data were collected for 2 min. During the middle of the last steady state minute, subjects were asked to assess the RPE for their legs, chest, and overall body.

Between each resistance setting, the subjects exercised slowly on the elliptical machine at the lowest resistance until their HR recovered to 110 bpm. When HR decreased to 110 bpm or less, the subjects performed the next experimental condition.

Treatment of Data

HR, relative VO₂, and R values were sampled every 20 sec for 2 min once steady state was achieved. Means for HR, relative VO₂, and R value were found by averaging the values for the two steady state minutes. To determine HR as a percentage of maximum HR and relative VO₂ as a percentage of VO₂ max, subjects’ mean HR and relative VO₂ for each experimental condition were divided by their maximum HR and VO₂ max, respectively, as determined by the maximal treadmill test. The mean R value was used to calculate absolute energy cost. A nonprotein R table (Robergs & Roberts, 1997) was used to determine the kcal equivalent value per liter of oxygen consumed. That value was multiplied by the mean VO₂ in liters per min to find absolute energy cost during each experimental condition. That value was divided by body weight to determine relative energy cost.
Split plot factorial ANOVAs were calculated to determine if the dependent variables were significantly different between the experimental conditions. Tukey's LSD (Least Significant Difference) post-hoc tests were calculated to determine between which grades and resistance levels significant differences existed. All statistical hypotheses were tested at the .05 level of significance.
CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to measure and compare the physiological and perceptual responses to exercise on a Precor elliptical trainer at three different grade and resistance levels. Participants exercised at each experimental condition for 5 min. Data were collected during the final 2 min. The following results are presented in this chapter: (a) subject demographics, (b) HR, (c) HR as a percentage of maximum HR, (d) relative VO₂, (e) relative VO₂ as a percentage of VO₂ max, (f) absolute energy cost, (g) relative energy cost, (h) RPE for legs, (i) RPE for chest, and (j) RPE for overall body.

Results

Subject Demographics

Thirty subjects completed the study, 10 males and 20 females. The mean age of the males was 23.2 years with a standard deviation of 3.2 years. The mean age of the females was 22.4 years with a standard deviation of 2.9 years. The mean height for males was 1.8 m with a standard deviation of 0.06 m. The mean height for females was 1.7 m with a standard deviation of 0.08 m. The mean weight for males was 80.2 kg with a standard deviation of 11.7 kg. The mean weight for females was 64.8 kg with a standard deviation of 10.8 kg. The mean maximum HR for males was
191.1 bpm with a standard deviation of 8.7 bpm. The mean maximum HR for females was 187.5 bpm with a standard deviation of 10.6 bpm. The mean VO$_2$ max for males was 49.2 ml · kg$^{-1}$ · min$^{-1}$ with a standard deviation of 7.7 ml · kg$^{-1}$ · min$^{-1}$. The mean VO$_2$ max for females was 42.1 ml · kg$^{-1}$ · min$^{-1}$ with a standard deviation of 5.1 ml · kg$^{-1}$ · min$^{-1}$.

Heart Rate

A split plot factorial ANOVA was calculated to analyze HR. The ANOVA summary table is presented in Table 1. There was no significant difference between genders, $F(1, 28) = 0.82, p = .374$. The mean HR for males and females were 135.9 and 140.9 bpm, respectively. The ANOVA revealed a significant difference among grades, $F(2, 56) = 6.81, p = .002$. The mean HR for G4, G8, and G12 were 134.0, 139.8, and 141.4 bpm, respectively. A Tukey LSD post-hoc test indicated significant differences existed between the following: (a) G4 and G8, and (b) G4 and G12. There was a significant difference among resistances, $F(2, 56) = 141.15, p = .000$. The mean HR for R4, R8, and R12 were 125.9, 135.1, and 154.3 bpm, respectively. A Tukey LSD post-hoc test indicated significant differences between the following: (a) R4 and R8, (b) R4 and R12, and (c) R8 and R12. No significant interaction effects were found.
### Table 1

**ANOVA Summary for Heart Rate**

<table>
<thead>
<tr>
<th>Source</th>
<th>$MS$</th>
<th>$df$</th>
<th>$MS$</th>
<th>$F$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>1450.42</td>
<td>1</td>
<td>1450.42</td>
<td>0.82</td>
<td>.374</td>
</tr>
<tr>
<td>Error</td>
<td>49693.81</td>
<td>28</td>
<td>1774.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade (G)</td>
<td>2419.16</td>
<td>2</td>
<td>1209.58</td>
<td>6.81</td>
<td>.002</td>
</tr>
<tr>
<td>$G \times$ Gender</td>
<td>322.88</td>
<td>2</td>
<td>164.440</td>
<td>0.91</td>
<td>.409</td>
</tr>
<tr>
<td>Error (G)</td>
<td>9946.08</td>
<td>56</td>
<td>177.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance (R)</td>
<td>33641.47</td>
<td>2</td>
<td>16820.74</td>
<td>141.15</td>
<td>.00</td>
</tr>
<tr>
<td>$R \times$ Gender</td>
<td>724.48</td>
<td>2</td>
<td>362.24</td>
<td>3.04</td>
<td>.056</td>
</tr>
<tr>
<td>Error (R)</td>
<td>6673.28</td>
<td>56</td>
<td>119.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$G \times$ R</td>
<td>460.152</td>
<td>4</td>
<td>115.04</td>
<td>1.27</td>
<td>.286</td>
</tr>
<tr>
<td>$G \times$ R $\times$ Gender</td>
<td>32.48</td>
<td>4</td>
<td>8.12</td>
<td>0.09</td>
<td>.986</td>
</tr>
<tr>
<td>Error (G $\times$ R)</td>
<td>10152.39</td>
<td>112</td>
<td>90.65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**HR as a Percentage of Maximum HR**

A split plot factorial ANOVA was calculated to analyze HR as a percentage of maximum HR. The ANOVA summary table is presented in Table 2. There was no significant difference between genders, $F(1, 28) = 2.02$, $p = .166$. The mean percentages of maximum HR for males and females were 71.4 and 75.1%, respectively. The ANOVA showed significant differences among grades, $F(2, 56) =$
Table 2

ANOVA Summary for Heart Rate as a Percentage of Maximum Heart Rate

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>833.88</td>
<td>1</td>
<td>833.88</td>
<td>2.02</td>
<td>.166</td>
</tr>
<tr>
<td>Error</td>
<td>11541.67</td>
<td>28</td>
<td>412.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade (G)</td>
<td>718.17</td>
<td>2</td>
<td>359.08</td>
<td>6.39</td>
<td>.003</td>
</tr>
<tr>
<td>G x Gender</td>
<td>89.26</td>
<td>2</td>
<td>44.63</td>
<td>.79</td>
<td>.457</td>
</tr>
<tr>
<td>Error (G)</td>
<td>3148.01</td>
<td>56</td>
<td>56.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance (R)</td>
<td>9603.94</td>
<td>2</td>
<td>4801.97</td>
<td>142.11</td>
<td>.000</td>
</tr>
<tr>
<td>R x Gender</td>
<td>310.14</td>
<td>2</td>
<td>155.07</td>
<td>4.59</td>
<td>.014</td>
</tr>
<tr>
<td>Error (R)</td>
<td>1892.30</td>
<td>56</td>
<td>33.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G x R</td>
<td>155.41</td>
<td>4</td>
<td>38.85</td>
<td>1.97</td>
<td>.104</td>
</tr>
<tr>
<td>G x R x Gender</td>
<td>3.29</td>
<td>4</td>
<td>0.82</td>
<td>0.04</td>
<td>.997</td>
</tr>
<tr>
<td>Error (G x R)</td>
<td>2210.64</td>
<td>112</td>
<td>19.74</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.39, \( p = .003 \). The mean percentages of maximum HR for G4, G8, and G12 were 70.8, 74.1, and 74.8%, respectively. A Tukey LSD post-hoc test revealed significant differences between the following: (a) G4 and G8, and (b) G4 and G12. There also was a significant difference among resistances, \( F(2, 56) = 142.11, p = .000 \). The mean percentages of maximum HR for R4, R8, and R12 were 66.4, 71.7, and 81.7%, respectively. A Tukey LSD post-hoc test indicated significant differences between the following: (a) R4 and R8, (b) R4 and R12, and (c) R8 and R12. A
A significant interaction effect was found between resistance by gender, $F(2, 56) = 4.59, p = .014$. The mean percentages of maximum HR for males at R4, R8, and R12 were 66.0, 69.5, and 78.6%, respectively. The mean percentages of maximum HR for females at R4, R8, and R12 were 66.7, 73.9, and 84.7%, respectively. No other significant interaction effects were found.

Relative VO$_2$

A split plot factorial ANOVA was calculated to analyze relative VO$_2$. The ANOVA summary is shown in Table 3. There was no significant difference between genders, $F(1, 28) = .000, p = .983$. The mean relative VO$_2$ for males and females were 20.08 and 20.10 ml·kg$^{-1}$·min$^{-1}$, respectively. The ANOVA revealed a significant difference in relative VO$_2$ among grades, $F(2, 56) = 6.71, p = .002$. The mean relative VO$_2$ for G4, G8, and G12 were 19.3, 20.4, and 20.6 ml·kg$^{-1}$·min$^{-1}$, respectively. A Tukey LSD post-hoc test indicated significant differences existed between the following: (a) G4 and G8, and (b) G4 and G12. The ANOVA showed a significant difference among resistances, $F(2, 56) = 316.21, p = .000$. The mean relative VO$_2$ for R4, R8, and R12 were 15.6, 18.5, and 26.1 ml·kg$^{-1}$·min$^{-1}$, respectively. The Tukey LSD post-hoc test indicated significant differences between the following: (a) R4 and R8, (b) R4 and R12, and (c) R8 and R12. A significant interaction effect was found between resistance by gender, $F(2, 56) = 14.49, p = .000$. The mean relative VO$_2$ for males at R4, R8, and R12 were 16.7, 18.7, and
Table 3
ANOVA Summary for Relative VO₂

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>0.0135</td>
<td>1</td>
<td>0.0135</td>
<td>.000</td>
<td>.983</td>
</tr>
<tr>
<td>Error</td>
<td>866.48</td>
<td>28</td>
<td>30.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade (G)</td>
<td>74.51</td>
<td>2</td>
<td>37.26</td>
<td>6.71</td>
<td>.002</td>
</tr>
<tr>
<td>G x Gender</td>
<td>32.73</td>
<td>2</td>
<td>16.37</td>
<td>2.94</td>
<td>.061</td>
</tr>
<tr>
<td>Error (G)</td>
<td>310.80</td>
<td>56</td>
<td>5.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance (R)</td>
<td>4663.22</td>
<td>2</td>
<td>2331.61</td>
<td>316.21</td>
<td>.000</td>
</tr>
<tr>
<td>R x Gender</td>
<td>213.67</td>
<td>2</td>
<td>106.84</td>
<td>14.49</td>
<td>.000</td>
</tr>
<tr>
<td>Error (R)</td>
<td>412.93</td>
<td>56</td>
<td>7.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G x R</td>
<td>12.61</td>
<td>4</td>
<td>3.15</td>
<td>2.00</td>
<td>.099</td>
</tr>
<tr>
<td>G x R x Gender</td>
<td>2.128</td>
<td>4</td>
<td>0.53</td>
<td>0.34</td>
<td>.852</td>
</tr>
<tr>
<td>Error (G x R)</td>
<td>176.27</td>
<td>112</td>
<td>1.57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

24.8 ml · kg⁻¹ · min⁻¹, respectively. The mean relative VO₂ for females at R4, R8, and R12 were 14.6, 18.3, and 27.3 ml · kg⁻¹ · min⁻¹, respectively. No other significant interaction effects were found.
Relative VO\textsubscript{2} as a Percentage of VO\textsubscript{2} Max

A split plot factorial ANOVA was calculated to analyze relative VO\textsubscript{2} as a percentage of VO\textsubscript{2} max. The ANOVA summary is presented in Table 4. The ANOVA revealed a significant difference between genders, $F(1, 28) = 9.43, p = .005$. The mean percentages of VO\textsubscript{2} max for males and females were 41.4 and 48.2\%, respectively. There was a significant difference among grades, $F(2, 56) = 6.69, p = .002$. The mean percentages of VO\textsubscript{2} max for G4, G8, and G12 were 43.1, 45.3, and 46.0\%, respectively. A Tukey LSD post-hoc test indicated significant differences existed between the following: (a) G4 and G8, and (b) G4 and G12. The ANOVA showed a significant difference among resistances, $F(2, 56) = 313.68, p = .000$. The mean percentages of VO\textsubscript{2} max for R4, R8, and R12 were 35.0, 41.1, and 58.2\%, respectively. A Tukey LSD post-hoc test indicated significant differences between the following: (a) R4 and R8, (b) R4 and R12, and (c) R8 and R12. A significant interaction effect was found between resistance by gender. The mean percentages of VO\textsubscript{2} max for males at R4, R8, and R12 were 34.8, 38.2, and 51.2\%, respectively. The mean percentages of VO\textsubscript{2} max for females at R4, R8, and R12 were 35.2, 44.0, and 65.2\%, respectively. A significant interaction effect was found between grade by resistance, $F(4, 112) = 2.47, p = .048$. The mean percentages of VO\textsubscript{2} max for G4 at R4, R8, and R12 were 32.2, 39.8, and 57.4\%, respectively. The mean percentages of VO\textsubscript{2} max for G8 at R4, R8, and R12 were 36.3, 41.0, and
58.4%, respectively. The mean percentages of VO₂ max for G1 at R4, R8, and R12 were 36.5, 42.6, and 58.9%, respectively. No other significant interaction effects were found.

Table 4

ANOVA Summary for VO₂ as a Percentage of Maximum VO₂

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>2725.07</td>
<td>1</td>
<td>2725.07</td>
<td>9.43</td>
<td>.005</td>
</tr>
<tr>
<td>Error</td>
<td>8093.66</td>
<td>28</td>
<td>289.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade (G)</td>
<td>359.54</td>
<td>2</td>
<td>179.77</td>
<td>6.69</td>
<td>.002</td>
</tr>
<tr>
<td>G × Gender</td>
<td>138.85</td>
<td>2</td>
<td>69.42</td>
<td>2.58</td>
<td>.085</td>
</tr>
<tr>
<td>Error (G)</td>
<td>1506.02</td>
<td>56</td>
<td>26.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance (R)</td>
<td>23209.22</td>
<td>2</td>
<td>11604.61</td>
<td>313.68</td>
<td>.000</td>
</tr>
<tr>
<td>R × Gender</td>
<td>1875.92</td>
<td>2</td>
<td>937.96</td>
<td>25.35</td>
<td>.000</td>
</tr>
<tr>
<td>Error (R)</td>
<td>2071.71</td>
<td>56</td>
<td>36.995</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G × R</td>
<td>95.61</td>
<td>4</td>
<td>23.90</td>
<td>2.47</td>
<td>.048</td>
</tr>
<tr>
<td>G × R × Gender</td>
<td>10.15</td>
<td>4</td>
<td>2.54</td>
<td>0.26</td>
<td>.901</td>
</tr>
<tr>
<td>Error (G × R)</td>
<td>1082.55</td>
<td>112</td>
<td>9.67</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Absolute Energy Cost

A split plot factorial ANOVA was calculated to analyze absolute energy cost. The ANOVA summary is shown in Table 5. A significant difference was found
Table 5

ANOVA Summary for Relative Energy Cost (kcal · min⁻¹)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>143.24</td>
<td>1</td>
<td>143.24</td>
<td>23.19</td>
<td>.000</td>
</tr>
<tr>
<td>Error</td>
<td>172.95</td>
<td>28</td>
<td>6.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade (G)</td>
<td>11.69</td>
<td>2</td>
<td>5.84</td>
<td>8.35</td>
<td>.001</td>
</tr>
<tr>
<td>G × Gender</td>
<td>4.02</td>
<td>2</td>
<td>2.008</td>
<td>2.87</td>
<td>.065</td>
</tr>
<tr>
<td>Error (G)</td>
<td>39.19</td>
<td>56</td>
<td>0.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance (R)</td>
<td>545.53</td>
<td>2</td>
<td>272.77</td>
<td>329.29</td>
<td>.000</td>
</tr>
<tr>
<td>R × Gender</td>
<td>7.64</td>
<td>2</td>
<td>3.82</td>
<td>5.49</td>
<td>.007</td>
</tr>
<tr>
<td>Error (R)</td>
<td>38.94</td>
<td>56</td>
<td>0.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G × R</td>
<td>4.81</td>
<td>4</td>
<td>1.20</td>
<td>2.88</td>
<td>.026</td>
</tr>
<tr>
<td>G × R × Gender</td>
<td>1.49</td>
<td>4</td>
<td>0.37</td>
<td>0.89</td>
<td>.473</td>
</tr>
<tr>
<td>Error (G × R)</td>
<td>46.77</td>
<td>112</td>
<td>0.418</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

between genders, $F(1, 28) = 23.19, p = .000$. The mean absolute energy cost for males and females were 7.9 and 6.4 kcal · min⁻¹, respectively. The ANOVA showed a significant difference in energy cost among grades, $F(2, 56) = 8.35, p = .001$. The mean absolute energy cost for G4, G8, and G12 were 6.9, 7.3, and 7.4 kcal · min⁻¹, respectively. A Tukey LSD post-hoc test indicated significant differences between
the following: (a) G4 and G8, and (b) G4 and G12. There was a significant difference among resistances, $F(2, 56) = 329.29, p = 0.000$. The mean absolute energy cost for R4, R8, and R12 were 5.7, 6.6, and 9.2 kcal $\cdot$ min$^{-1}$, respectively. The Tukey LSD post-hoc tests revealed that significant differences existed between the following: (a) R4 and R8, (b) R4 and R12, and (c) R8 and R12. A significant interaction effect was found between resistance by gender, $F(2, 56) = 5.49, p = 0.007$. The mean absolute energy cost for males at R4, R8, and R12 were 6.7, 7.3, and 9.9 kcal $\cdot$ min$^{-1}$, respectively. The mean energy cost for females at R4, R8, and R12 were 4.6, 5.9, and 8.6 kcal $\cdot$ min$^{-1}$, respectively. A significant interaction effect was also found between grade by resistance, $F(4, 112) = 2.88, p = 0.026$. The mean absolute energy cost of G4 at R4, R8, and R12 were 5.1, 6.3, and 9.1 kcal $\cdot$ min$^{-1}$, respectively. The mean absolute energy cost of G8 at R4, R8, and R12 were 6.0, 6.7, and 9.1 kcal $\cdot$ min$^{-1}$, respectively. The mean absolute energy cost of G12 at R4, R8, and R12 were 5.9, 6.8, and 9.4 kcal $\cdot$ min$^{-1}$, respectively. No other significant interaction effects were found.

**Relative Energy Cost**

A split plot factorial ANOVA was calculated to analyze relative energy cost. The ANOVA summary is presented in Table 6. There was no significant difference between genders, $F(1, 28) = 0.017, p = 0.896$. The mean relative energy cost for males and females were 0.0994 and 0.0999 kcal $\cdot$ kg$^{-1} \cdot$ min$^{-1}$, respectively. The
Table 6
ANOVA Summary for Relative Energy Cost (kcal · kg\(^{-1}\) · min\(^{-1}\))

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>0.00001402</td>
<td>1</td>
<td>0.00001402</td>
<td>0.017</td>
<td>.896</td>
</tr>
<tr>
<td>Error</td>
<td>0.0265</td>
<td>28</td>
<td>0.000809</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade (G)</td>
<td>0.001895</td>
<td>2</td>
<td>0.000947</td>
<td>7.17</td>
<td>.002</td>
</tr>
<tr>
<td>G × Gender</td>
<td>0.000576</td>
<td>2</td>
<td>0.000288</td>
<td>2.18</td>
<td>.123</td>
</tr>
<tr>
<td>Error (G)</td>
<td>0.007403</td>
<td>56</td>
<td>0.0001322</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance (R)</td>
<td>0.118</td>
<td>2</td>
<td>0.05894</td>
<td>272.02</td>
<td>.000</td>
</tr>
<tr>
<td>R × Gender</td>
<td>0.006365</td>
<td>2</td>
<td>0.003182</td>
<td>14.69</td>
<td>.000</td>
</tr>
<tr>
<td>Error (R)</td>
<td>0.000121</td>
<td>56</td>
<td>0.0002167</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G × R</td>
<td>0.0000578</td>
<td>4</td>
<td>0.0001445</td>
<td>3.05</td>
<td>.020</td>
</tr>
<tr>
<td>G × R × Gender</td>
<td>0.000192</td>
<td>4</td>
<td>0.0000479</td>
<td>1.01</td>
<td>.404</td>
</tr>
<tr>
<td>Error (G × R)</td>
<td>0.005302</td>
<td>112</td>
<td>0.0000473</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ANOVA revealed a significant difference among grades, \(F(2, 56) = 7.17, \ p = .002\).

The mean relative energy cost for G4, G8, and G12 were 0.0957, 0.1010, and 0.1020 kcal · kg\(^{-1}\) · min\(^{-1}\), respectively. A Tukey LSD post-hoc tested indicated significant differences existed between the following: (a) G4 and G8, and (b) G4 and G12. The ANOVA also revealed a significant difference among resistances, \(F(2, 56) = 272.02, \ p = 0.000\). The mean relative energy cost for R4, R8, and R12 were 0.0778,
0.0911, and 0.1300 kcal·kg\(^{-1}\)·min\(^{-1}\), respectively. A Tukey LSD post-hoc test showed that significant differences existed between the following: (a) R4 and R8, (b) R4 and R12, (c) R8 and R12. The ANOVA found a significant interaction effect between resistance by gender, \(F(2, 56) = 14.69, p = .000\). The mean relative energy cost for males at R4, R8, and R12 were 0.0834, 0.0916, and 0.1230 kcal·kg\(^{-1}\)·min\(^{-1}\), respectively. The mean relative energy cost for females at R4, R8, and R12 were 0.0721, 0.0907, and 0.1370 kcal·kg\(^{-1}\)·min\(^{-1}\), respectively. There also was a significant interaction effect found between grade by resistance, \(F(4, 112) = 3.05, p = .020\). The mean relative energy cost of G4 at R4, R8, and R12 were 0.0712, 0.0877, and 0.1280 kcal·kg\(^{-1}\)·min\(^{-1}\), respectively. The mean relative energy cost of G8 at R4, R8, and R12 were 0.0815, 0.0915, and 0.1300 kcal·kg\(^{-1}\)·min\(^{-1}\), respectively. The mean relative energy cost of G12 at R4, R8, and R12 were 0.0860, 0.0943, and 0.1320 kcal·kg\(^{-1}\)·min\(^{-1}\), respectively. No other significant interaction effects were found.

**RPE for Legs**

A split plot factorial ANOVA was calculated to analyze RPE for legs. The ANOVA summary is presented in Table 7. The ANOVA showed no significant difference between genders, \(F(1, 28) = 3.98, p = .056\). The mean RPE for legs for males and females were 8.0 and 8.9, respectively. There was a significant difference in RPE among grades, \(F(2, 56) = 4.40, p = .017\). The mean RPE for legs for G4,
Table 7
ANOVA Summary for RPE for Legs

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>49.81</td>
<td>1</td>
<td>49.81</td>
<td>3.98</td>
<td>.056</td>
</tr>
<tr>
<td>Error</td>
<td>350.88</td>
<td>28</td>
<td>12.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade (G)</td>
<td>24.05</td>
<td>2</td>
<td>12.02</td>
<td>4.40</td>
<td>.017</td>
</tr>
<tr>
<td>G × Gender</td>
<td>1.38</td>
<td>2</td>
<td>0.69</td>
<td>0.25</td>
<td>.778</td>
</tr>
<tr>
<td>Error (G)</td>
<td>153.06</td>
<td>56</td>
<td>2.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance (R)</td>
<td>169.29</td>
<td>2</td>
<td>84.65</td>
<td>29.14</td>
<td>.000</td>
</tr>
<tr>
<td>R × Gender</td>
<td>44.00</td>
<td>2</td>
<td>22.00</td>
<td>7.58</td>
<td>.001</td>
</tr>
<tr>
<td>Error (R)</td>
<td>162.66</td>
<td>56</td>
<td>2.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G × R</td>
<td>3.17</td>
<td>4</td>
<td>0.79</td>
<td>0.95</td>
<td>.441</td>
</tr>
<tr>
<td>G × R × Gender</td>
<td>2.24</td>
<td>4</td>
<td>0.56</td>
<td>0.67</td>
<td>.616</td>
</tr>
<tr>
<td>Error (G × R)</td>
<td>94.01</td>
<td>112</td>
<td>0.84</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

G8, and G12 were 8.1, 8.3, and 8.9, respectively. A Tukey post-hoc test indicated significant differences existed between the following: (a) G4 and G12, and (b) G8 and G12. The ANOVA revealed a significant difference among resistances, \( F(2, 56) = 29.14, p = .000 \). The mean RPE for legs for R4, R8, and R12 were 7.6, 8.1, and 9.6 respectively. The Tukey LSD post-hoc tests indicated significant differences existed between the following: (a) R4 and R8, (b) R4 and R12, and (c) R8 and R12. The ANOVA showed significant interaction effects between resistance by gender,
$F(2, 56) = 7.58, p = .001$. The mean RPE for legs for males at R4, R8, and R12 were 7.6, 7.8, and 8.5, respectively. The RPE for legs for females at R4, R8, and R12 were 7.7, 8.3, and 10.6, respectively. No other interaction effects were found.

**RPE for Chest**

A split plot factorial ANOVA was calculated to analyze RPE of the chest. The ANOVA summary is presented in Table 8. The ANOVA showed there was no significant difference between genders, $F(1, 28) = 2.66, p = .114$. The mean RPE for chest for males and females were 7.8 and 8.8, respectively. There also was no significant difference among grades, $F(2, 56) = 0.52, p = .600$. The mean RPE for chest for G4, G8, and G12 were 8.0, 8.4, and 8.5, respectively. The ANOVA revealed a significant difference among resistances, $F(2, 56) = 15.52, p = .000$. The RPE for chest for R4, R8, and R12 were 7.6, 8.0, and 9.4, respectively. The Tukey post-hoc test showed significant differences existed between the following: (a) R4 and R12, and (b) R8 and R12. The ANOVA showed a significant interaction effect between resistance by gender, $F(2, 56) = 5.75, p = .005$. The mean RPE for chest for males at R4, R8, and R12 were 7.4, 7.6, and 7.9, respectively. The RPE for chest for females at R4, R8, and R12 were 7.5, 8.0, and 9.6, respectively. No other significant interaction effects were found.
Table 8
ANOVA Summary for RPE for Chest

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>31.78</td>
<td>1</td>
<td>31.78</td>
<td>2.66</td>
<td>.114</td>
</tr>
<tr>
<td>Error</td>
<td>334.91</td>
<td>28</td>
<td>11.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade (G)</td>
<td>2.31</td>
<td>2</td>
<td>1.16</td>
<td>0.52</td>
<td>.600</td>
</tr>
<tr>
<td>G x Gender</td>
<td>2.90</td>
<td>2</td>
<td>1.45</td>
<td>0.65</td>
<td>.527</td>
</tr>
<tr>
<td>Error (G)</td>
<td>125.44</td>
<td>56</td>
<td>2.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance (R)</td>
<td>78.21</td>
<td>2</td>
<td>39.12</td>
<td>15.52</td>
<td>.000</td>
</tr>
<tr>
<td>R x Gender</td>
<td>28.98</td>
<td>2</td>
<td>14.49</td>
<td>5.75</td>
<td>.005</td>
</tr>
<tr>
<td>Error (R)</td>
<td>141.14</td>
<td>56</td>
<td>2.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G x R</td>
<td>3.51</td>
<td>4</td>
<td>0.88</td>
<td>0.90</td>
<td>.469</td>
</tr>
<tr>
<td>G x R x Gender</td>
<td>4.519</td>
<td>4</td>
<td>1.13</td>
<td>1.15</td>
<td>.336</td>
</tr>
<tr>
<td>Error (G x R)</td>
<td>109.76</td>
<td>112</td>
<td>0.98</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

RPE for Overall Body

A split plot factorial ANOVA was calculated to analyze RPE for overall body. The ANOVA summary is presented in Table 9. There was no significant difference between genders, $F(1, 28) = 3.91, p = .058$. The mean overall RPE for males and females were 7.6 and 8.4, respectively. The ANOVA showed there was no significant difference among grades, $F(2, 56) = 2.78, p = .071$. The mean overall
Table 9
ANOVA Summary for RPE for Overall Body

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>52.89</td>
<td>1</td>
<td>52.89</td>
<td>3.91</td>
<td>.058</td>
</tr>
<tr>
<td>Error</td>
<td>378.38</td>
<td>28</td>
<td>13.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade (G)</td>
<td>13.25</td>
<td>2</td>
<td>6.62</td>
<td>2.78</td>
<td>.071</td>
</tr>
<tr>
<td>G × Gender</td>
<td>2.05</td>
<td>2</td>
<td>1.02</td>
<td>0.43</td>
<td>.653</td>
</tr>
<tr>
<td>Error (G)</td>
<td>41.29</td>
<td>56</td>
<td>2.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance (R)</td>
<td>140.00</td>
<td>2</td>
<td>70.00</td>
<td>23.55</td>
<td>.000</td>
</tr>
<tr>
<td>R × Gender</td>
<td>41.29</td>
<td>2</td>
<td>20.96</td>
<td>7.05</td>
<td>.002</td>
</tr>
<tr>
<td>Error (R)</td>
<td>166.43</td>
<td>56</td>
<td>2.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G × R</td>
<td>2.76</td>
<td>4</td>
<td>0.69</td>
<td>0.91</td>
<td>.460</td>
</tr>
<tr>
<td>G × R × Gender</td>
<td>1.16</td>
<td>4</td>
<td>0.29</td>
<td>0.38</td>
<td>.820</td>
</tr>
<tr>
<td>Error (G × R)</td>
<td>84.87</td>
<td>112</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

RPE for G4, G8, and G12 were 7.9, 8.0, and 8.1, respectively. A significant difference was found among resistances, $F(2, 56) = 23.55, p = .000$. The mean overall RPE for R4, R8, and R12 were 7.4, 7.8, and 8.8, respectively. A Tukey LSD post-hoc test indicated significant differences existed between the following: (a) R4 and R12, and (b) R8 and R12. The ANOVA found a significant interaction effect between resistance by gender, $F(2, 56) = 7.05, p = .002$. The mean overall RPE for
males at R4, R8, and R12 were 7.5, 7.7, and 8.3, respectively. The mean overall 
RPE for females at R4, R8, and R12 were 7.6, 8.3, and 10.4, respectively. No other 
significant interaction effects were found.

Discussion

Many of the research results indicated significant differences in physiological 
and perceptual responses among the various elliptical trainer grade and resistance 
settings utilized. The discussion includes the following topics: (a) HR, (b) HR as a 
percentage of maximum HR, (c) relative VO₂, (d) relative VO₂ as a percentage of 
VO₂ max, (e) absolute and relative energy cost, (f) RPE for legs, chest, and overall 
body, and (g) summary.

Heart Rate

Heart rate increased as the grade increased. The increase was significant 
between G4 and G8 and G4 and G12, but was not significant between G8 and G12. 
This indicated that increasing the grade from a relatively flat grade (G4) to a 
medium-low to medium-high grade (G8 and G12, respectively) increased work 
intensity and, therefore, HR. Further increases in grade from G8 to G12, however, 
did not elicit a significantly greater HR response. The insignificant increase in HR 
from G8 to G12 could be a result of the effect of gravity on the downward phase of 
the pedal stride. At greater grades, one needs to work harder during the climbing 
phase of the stride, but the influence of gravity on the downward phase increases as
the grade increases; this somewhat counterbalances the increased work on the climbing phase. Heart rate also increased as resistance increased. The increase was significant between each of the pair-wise comparisons, indicating each subsequent increase in resistance increased workload, which resulted in higher HR responses.

The present study’s results paralleled the findings of other elliptical trainer research. Kravitz et al. (1998) found that an increase in grade increased HR from 145.3 to 154.2 bpm. Also, an increase in resistance resulted in an even greater increase in HR than increased grade, from 145.3 to 166.9 bpm. Reported mean HR elicited from submaximal elliptical trainer exercise varied greatly depending on the research methodology and ranged from 130.4 bpm (Pecchia et al., 1999) to 166.9 bpm (Kravitz et al., 1998). The mean HRs observed in the present study were somewhat lower or similar to previous research, depending on the grade and resistance setting used. The HR in this study ranged from 120.1 bpm (mean of all subjects at G4 R4) to 157.1 bpm (mean of all subjects at G12 R12). The lower HR measured in this study appeared to be a result of the lower grade and resistance levels utilized compared to other research.

HR as a Percentage of Maximum HR

Exercise HR measured at each grade and resistance level were divided by maximum HR to calculate HR as a percentage of maximum HR. Percentage of maximum HR increased as grade increased. Similar to HR, the increase in percentage of maximum HR was significant between G4 and G8, and G4 and G12,
but was not significant between G8 and G12. This again suggested that after a certain point, an increase in the grade did not necessarily result in an increase in work intensity. Percentage of maximum HR also increased as resistance increased. The difference in percentages was significant between each of the pair-wise comparisons, indicating intensity increased with each subsequent increase in resistance.

There was an interaction effect for resistance by gender. The percentages of maximum HR for males and females were similar at R4. However, at R8 and R12, females displayed a greater percentage of maximum HR than males. Since there was not a significant interaction effect for resistance by gender for HR, the significant interaction effect for percentage of maximum HR could be a result of the differences in maximum HR between genders. The mean maximum HR for males was greater than for females. In addition, males had a slightly lower, but not statistically significant, mean exercise HR than females. Thus, the result would be lower percentages of maximum HR for males.

ACSM guidelines recommend exercising at an intensity of 55 to 90% of maximum HR to improve or maintain cardiovascular fitness. All conditions used in this study elicited a percentage of maximum HR within the ACSM recommendations. The percentages of maximum HR observed in the present study were similar to those cited by Cotton (1998).
Relative VO₂

Relative VO₂ increased as grade increased. Similar to the other variables discussed, the increase was significant between G4 and G8, and G4 and G12, but was not significant between G8 and G12. In fact, mean relative VO₂ values for G8 and G12 were nearly identical: 20.4 and 20.6 ml • kg⁻¹ • min⁻¹, respectively. Again, this showed that an increase in grade from a medium-low grade to a medium-high grade did not significantly increase workload. Relative VO₂ increased as resistance increased. The increase was significant between each of the pair-wise comparisons, indicating workout intensity increased as the resistance was increased.

Kravitz et al. (1998) found an increase in relative VO₂ from 22.3 to 23.6 ml • kg⁻¹ • min⁻¹ when grade was increased. Their research also showed that increased resistance had a greater influence on relative VO₂ than increased grade. The higher resistance used in their research increased relative VO₂ from 22.3 ml • kg⁻¹ • min⁻¹ to 29.6 ml • kg⁻¹ • min⁻¹. These results were similar to the present study in which both increased grade and resistance levels increased relative VO₂, and the effects of higher resistances were more significant than higher grades. Relative VO₂ values cited in various elliptical trainer research literature ranged from 22.1 ml • kg⁻¹ • min⁻¹ (Bakken, 1997) to 31.5 ml • kg⁻¹ • min⁻¹ (Porcari et al., 1998). The large differences among the values are most likely due to variations in methodology. The
relative VO\textsubscript{2} values measured in the present study ranged from 14.3 ml \cdot kg\textsuperscript{-1} \cdot min\textsuperscript{-1} (mean of all subjects at G4 R4) to 26.8 ml \cdot kg\textsuperscript{-1} \cdot min\textsuperscript{-1} (mean of all subjects at G12 R12). Those values were either lower than or similar to those found in other elliptical research. The lower grade and resistance levels used in the present study could account for the lower relative VO\textsubscript{2} values compared to the other research.

An interaction effect for relative VO\textsubscript{2} was found for gender by resistance. Elliptical trainer exercise elicited a slightly greater mean relative VO\textsubscript{2} values for males than females at R4 and R8. At R12, females had a somewhat greater mean relative VO\textsubscript{2} value than males. A similar response in relative VO\textsubscript{2} between genders was found by Butts, Dodge, and McAlpine (1993). Their research on stair-climbing machine stepping rates found the relative VO\textsubscript{2} for males was greater than for females. They proposed that the differences were due to stepping efficiency/mechanics or body composition differences between males and females.

In the present study, a possible explanation of the relative VO\textsubscript{2} differences between genders at R12 is related to body weight. The female subjects, in general, weighed less than the male subjects. Having greater body mass might have assisted individuals on the downward phase of the elliptical pedal cycle. As a result, males, with their greater body mass, may have been at an advantage and were not required to work as hard as females at R12. In addition, males had a greater mean VO\textsubscript{2} max than females indicating they were in better aerobic condition than the females. As a result, males may have worked more efficiently at R12 than females.
Relative VO\textsubscript{2} as a Percentage of VO\textsubscript{2} Max

The relative VO\textsubscript{2} found at each experimental condition were divided by VO\textsubscript{2} max to find relative VO\textsubscript{2} as a percentage of VO\textsubscript{2} max. A significant difference in percentage of VO\textsubscript{2} max was found between males and females. This could be explained by the differences in their VO\textsubscript{2} max estimates. The mean VO\textsubscript{2} max for males was greater than for females. An additional explanation for the significant difference in percentage of VO\textsubscript{2} max could be the gender differences in relative VO\textsubscript{2} at the different resistance levels.

Percentage of VO\textsubscript{2} max increased as grade increased. Similar to other physiological variables discussed, the differences were significant between G4 and G8, and G4 and G12, but not between G8 and G12. This further indicated that exercise intensity did not increase significantly once the grade was increased past a certain level. The percentage of VO\textsubscript{2} max also increased as resistance increased. The differences were significant between each pair-wise comparison. Again these results showed the influence that increased resistance had on increasing exercise intensity on the elliptical trainer.

There was a significant interaction effect for grade by resistance. At each grade, the percentage of VO\textsubscript{2} max increased as resistance increased. The percentages of VO\textsubscript{2} max elicited at G8 and G12 were similar to each other at the same resistance levels and greater than the percentages of VO\textsubscript{2} max elicited at G4.
However, the increase in the percentage of VO₂ max elicited as grade increased was not nearly as great as when resistance increased. This indicated that in order to significantly increase workout intensity on the elliptical trainer at a given grade and stride frequency, it was necessary to increase resistance levels.

ACSM guidelines for maintaining or improving cardiovascular fitness recommend working at an intensity of 50 to 85% of VO₂ max. In this study, the only conditions that fell in ACSM recommendations involved R12 at any of the three grades. It should be noted that these conditions elicited VO₂ max values that were at the lower end of the recommended range. Thus, it appears in order to work at an intensity great enough to improve cardiovascular fitness, it is necessary to use a medium-high resistance level when working at the stride frequency used in this study (130 spm). Interestingly, when using percentage of maximum HR as an indicator of workout intensity, all elliptical conditions fell within ACSM guidelines. That was unlike relative VO₂ as percentage of VO₂ max, in which only the three conditions using R12 met ACSM requirements for recommended workout intensity. In this study, it appeared that elliptical trainer exercise elicited greater HR than VO₂ responses at similar workloads. It is unknown why this occurred and similar responses were not observed in other research.

Pecchia et al. (1999) studied the physiological responses to exercise on an elliptical trainer compared to a treadmill at a set intensity of 55% VO₂ max, which was just less than the intensities found at R12 at G4, G8 or G12 in the present study.
The mean VO₂ and HR found in their study were comparable to the values measured in this study depending on gender, grade, and resistance level.

**Absolute and Relative Energy Cost**

Absolute energy cost was divided by body weight to calculate relative energy cost. This was done to eliminate differences in energy cost due to differences in body weight. Both absolute and relative energy cost increased as grade increased. The increase was significant between G4 and G8, and G4 and G12, but not between G8 and G12. As previously discussed, an increase in grade beyond a relatively flat grade did not significantly increase workload and thus did not require much additional energy to perform the exercise.

Absolute and relative energy cost also increased as resistance increased. The increase was significant between each of the pair-wise comparisons, especially between R8 and R12. The larger increase in energy expenditure between those resistance levels could be due to the greater workload at R12. Similar large increases were also seen in HR and relative VO₂ between those two resistance levels. It appeared the increase in physiological factors was nonlinear as resistance increased.

A significant interaction effect was found for grade by resistance. At each grade, absolute and relative energy cost increased as resistance increased. Looking at the same resistance levels, there was little increase in energy cost with an increase
in grade. This further illustrated that increased resistance had more of an influence on workload than increased grade.

There was a significant difference in absolute energy cost between males and females due to their differences in body weight. This difference was eliminated when relative energy cost was calculated. There was a significant interaction effect for gender by resistance for both relative and absolute energy cost. At each grade and resistance level, females had a lower absolute energy cost than males due to the females’ lower body weight. In terms of relative energy cost, males had a greater energy cost at R4 and R8, but females had a greater relative energy cost at R12. This was similar to the interaction effect between genders by resistance found in VO₂, in which females displayed at greater VO₂ at R12 than males. This could be explained by the differences in body weight and fitness levels between genders.

The absolute energy cost associated with elliptical trainer exercise in this study, depending on gender, grade, and resistance level, were less than or similar to absolute energy cost values found in other elliptical research. Absolute energy cost in the present study ranged from 4.9 kcal · min⁻¹ (mean of all subjects at G4R4) to 9.3 kcal · min⁻¹ (mean of all subjects at G12R12). In related literature, absolute energy cost ranged from 6.3 kcal · min⁻¹ (Bakken, 1997) to 11.5 kcal · min⁻¹ (Porcari et al., 1998). Similar to the present study, Kravitz et al. (1998) found a small increase in absolute energy cost with an increased grade (from 8.1 to 8.4 kcal ·
min⁻¹) and a larger increase with an increased resistance (from 8.1 to 10.7 kcal · min⁻¹).

RPE for Legs, Chest, and Overall Body

RPE was assessed for the legs, chest, and overall body to determine perceptual responses to exercise on the elliptical trainer. RPE for the legs, chest, and overall body increased as grade increased, but RPE for the legs was the only perceptual factor in which there was a significant difference among grades. The difference in RPE for legs existed between G4 and G12, and G8 and G12. At G12, the subjects perceived the workload to be somewhat harder for the legs than at G4 or G8. The difference in RPE for legs, although statistically significant, was very small. The difference between RPE of the legs at G4 and G12 was only 0.8 and between G8 and G12 it was only 0.6, not even a full point on the RPE scale.

The RPE for legs, chest, and overall body increased as resistance increased. For RPE for legs, the increase was significant between all pair-wise comparisons, and for RPE for chest and overall body the differences were significant between R4 and R12, and R8 and R12. The RPE for legs was significantly different between R4 and R8 possibly because on the elliptical trainer, the legs did the majority of the movement, and thus they were more sensitive to the increase in resistance. However, for all three types of RPEs, the increases from R4 to R8 were very small, 0.5 of a point or less, indicating not much of a difference was perceived between those two grades. Between R4 and R12, and R8 and R12, there was significant
increase in RPE of the legs, chest, and overall body. This indicated that exercising at the higher resistance level was perceived to be more difficult. Whereas RPE increased 0.5 or less between R4 and R8, RPE increased by at least 1 between R8 and R12. This increased RPE paralleled the increased physiological responses to exercise at the highest resistance level. As the resistance increased, the workload increased and that was reflected by both the physiological and perceptual responses. It is interesting to note that the mean RPEs of the legs and chest were greater than the RPE of the overall body. This could imply that the work felt in localized areas was perceived to be greater than the work output of the body as a whole. Kravitz et al. (1998) also found a slight increase in RPE with an increased grade (from 10.9 to 11.3) and a more substantial increase with increased resistance (from 10.9 to 13.4).

A significant interaction effect was found for gender by resistance across all three RPEs. Females perceived the elliptical trainer exercise to be harder than males at all resistance levels. This was especially evident at R12, in which the females’ RPEs were 1.7 to 2.1 points greater than the males’. This response in RPE correlated with the higher mean VO2 and relative energy cost at R12 for females as compared to males. This perceptual difference could be related to the differences in body weight and fitness levels between the genders as previously discussed.

Elliptical trainers have been noted for their lower perceived exercise exertion compared to other exercise modalities (Precor® USA, 1998; Sharp, 1999). In the present study, the RPE values were considerably low and ranged from approximately 7 (Very, very light) to 11 (Fairly light), depending on grade,
resistance, and gender. These values were below ACSM guidelines for perceived exercise intensity. ACSM recommends working at an RPE of 12 to 16. Explanations for the low RPEs in this study could include: (a) the subjects were regular exercisers, so they did not perceive the elliptical trainer exercise to be particularly strenuous; (b) the grades, resistance, and stride frequency used were not sufficient enough to produce RPEs within ACSM guidelines; (c) due to the nature of the elliptical machine, the exercise was perceived to be less strenuous than what the physiological responses indicated; and/or (d) the subjects did not accurately report their RPE due to lack of familiarity and understanding of the RPE scale.

RPE values reported in other elliptical research were higher than those found in the present study. Depending on research methodology, RPE in related literature ranged from 10.5 (Bakken, 1997) to 13.4 (Kravitz et al., 1998).

Summary

In this study, increasing the grade on the elliptical trainer caused an increase in physiological variables, although not always significantly. Increasing the resistance, however, more often than not, resulted in a significant increase in the physiological variables. Following is the order of exercise conditions in relation to their impact on physiological responses, from least to greatest: G4R4, G8R4, G12R4, G4R8, G8R8, G8R12, G4R12, G8R12, and G12R12. The order shows that it was level of resistance, not grade that had the greatest impact on elliptical trainer exercise workload.
The perceptual responses to elliptical trainer exercise were similar to the physiological response. RPE increased as grade and resistance increased, but not always significantly. Increases in resistance level, as opposed to grade, resulted in greater increases in RPE, especially of the legs.

Depending on the grade, resistance, and gender, the results of the present study were less than or similar to results found in previous research on the subject. It is difficult to make direct comparisons between the different research results, however, since this study examined differences between various grade and resistance levels specific to the Precor® EFX™ 546, a relatively new machine.
CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this study was to measure and compare physiological and perceptual responses to forward striding on an elliptical trainer at three different grade and resistance levels. The research is discussed under the following headings: (a) summary, (b) findings, (c) conclusions, and (d) recommendations.

Summary

This study examined the effects of elliptical trainer exercise on the following physiological and perceptual factors: (a) HR, (b) HR as a percentage of HR max, (c) relative VO₂, (d) VO₂ as a percentage of VO₂ max, (e) absolute energy cost, (f) relative energy cost, (g) RPE for legs, (h) RPE for chest, and (i) RPE for overall body. Thirty subjects, 10 males and 20 females, completed nine experimental conditions in random order: (1) G4R4, (2) G4R8, (3) G4R12, (4) G8R4, (5) G8R8, (6) G8R12, (7) G12R4, (8) G12R8, and (9) G12R12.

During the maximal treadmill testing and experimental conditions, HR was measured using a four-lead EKG. Relative VO₂ and R values were measured using a Sensormedics metabolic cart. Subjects strode forward on a Precor® EFX™ 546 elliptical trainer at 130 spm at the randomly selected grade and resistance settings for 5 min HR, relative VO₂, and R values were sampled every 20 sec, and the data
collected during the final 2 min were averaged. During the last minute of each condition, subjects were asked to assess RPE for their legs, chest, and overall body. HR as a percentage of maximum HR and relative VO₂ as a percentage of VO₂ max were calculated by dividing the mean values for each condition by the subject’s estimated maximum HR and VO₂ max, respectively. Absolute energy cost was calculated by consulting a nonprotein R table to determine the kcal equivalent value per liter of oxygen and multiplying that value by the mean VO₂ for the final 2 min of each experimental condition. Relative energy cost was calculated by dividing absolute energy cost by each subject’s body weight.

Split plot factorial ANOVAs were calculated for each of the dependent variables. All statistical hypotheses were tested at the .05 level of significance.

Findings

For the physiological factors, all of the research hypotheses were supported. Physiological factors were highest at G12 and lowest at G4. Likewise, physiological factors were highest at R12 and lowest at R4. For HR, the ANOVA showed no significant differences between genders, $F(1, 28) = 0.82, p = .374$. There was a significant difference among grades, $F(2, 56) = 6.81, p = .002$. A Tukey LSD post-hoc test revealed that significant differences existed between G4 and G8, and G4 and G12. The ANOVA showed a significant differences among resistances, $F(2, 56) = 141.15, p = .000$. A Tukey LSD post-hoc test indicated there were significant
differences between R4 and R8, R4 and R12, and R8 and R12. No significant interaction effects were found.

The ANOVA found no significant differences between genders for HR as a percentage of maximum HR, $F(1, 28) = 2.02, p = .166$. There was a significant difference among grades, $F(2, 56) = 6.39, p = .003$. A Tukey LSD post-hoc test showed significant differences existed between G4 and G8, and G4 and G12. The ANOVA also found significant differences among resistances, $F(2, 56) = 142.11, p = .000$. A Tukey LSD post-hoc test indicated significant differences existed between R4 and R8, R4 and R12, and R8 and R12. A significant interaction effect was found between resistance by gender, $F(2, 56) = 4.59, p = .014$. No other significant interaction effects were found.

For relative VO2, the ANOVA showed no significant differences between genders, $F(1, 28) = .000, p = .983$. The ANOVA did reveal a significant difference among grades, $F(2, 56) = 6.71, p = .002$. A Tukey LSD post-hoc test showed significant differences existed between G4 and G8, and G4 and G12. There also was a significant difference in relative VO2 among resistances, $F(2, 56) = 316.21, p = .000$. A Tukey LSD post-hoc test indicated significant differences existed between R4 and R8, R4 and R12, and R8 and R12. A significant interaction effect was found between resistance by gender, $F(2, 56) = 14.49, p = .000$. No other significant interaction effects were found.

The ANOVA revealed a significant difference in relative VO2 as a percentage of VO2 max between genders, $F(1, 28) = 9.43, p = .005$. There was a
significant difference among grades, $F(2, 56) = 6.69, p = .002$. A Tukey LSD post-hoc test indicated significant differences existed between G4 and G8, and G4 and G12. The ANOVA showed significant differences among resistances, $F(2, 56) = 313.68, p = .000$. A Tukey LSD post-hoc test showed that significant differences existed between R4 and R8, R4 and R12, and R8 and R12. A significant interaction effect was found between grade by resistance, $F(4, 112) = 2.47, p = .048$. No other significant interaction effects were found.

For absolute energy cost, there was a significant difference between genders, $F(1, 28) = 23.19, p = .000$. The ANOVA also showed a significant difference among grades, $F(2, 56) = 8.35, p = .001$. A Tukey LSD post-hoc test indicated significant differences existed between G4 and G8, and G4 and G12. There also was a significant difference in absolute energy cost among resistances, $F(2, 56) = 329.29, p = .000$. A Tukey LSD post-hoc test revealed significant differences existed between R4 and R8, R4 and R12, and R8 and R12. A significant interaction effect was found between resistance by gender, $F(2, 56) = 5.49, p = .007$. No other significant interaction effects were revealed.

The ANOVA showed no significant difference in relative energy cost between genders, $F(1, 28) = 0.017, p = .896$. There was a significant difference among grades, $F(2, 56) = 7.17, p = .002$. A Tukey LSD post-hoc test indicated significant differences existed between G4 and G8, and G4 and G12. There also was a significant difference in relative energy cost among resistances, $F(2, 56) = 272.02, p = .000$. A Tukey LSD post-hoc test showed significant differences existed between
R4 and R8, R4 and R12, R8 and R12. There were significant interaction effects between resistance by gender, $F(2, 56) = 14.69, p = .000$ and grade by resistance, $F(4, 112) = 3.05, p = .020$. For perceptual variables, not all of the research hypotheses were supported.

For RPE for legs, RPE was highest at G12 and R12 and lowest at G4 and R4. For RPE for chest and overall body, RPEs were highest at R12 and lowest at R4. However, there was no difference in RPE for chest or overall body among grades.

For RPE for legs, the ANOVA showed no significant difference between genders, $F(1, 28) = 3.98, p = .056$. There was a significant difference among grades, $F(2, 56) = 4.40, p = .017$. A Tukey LSD post-hoc test showed significant differences existed in RPE for legs between G4 and G12, and G8 and G12. The ANOVA also found a significant difference among resistances, $F(2, 56) = 29.14, p = .000$. A Tukey LSD post-hoc test indicated significant differences existed between R4 and R8, R4 and R12, and R8 and R12. There was a significant interaction effect found between resistance by gender, $F(2, 56) = 7.58, p = .001$. No other significant interaction effects were found.

The ANOVA showed no significant difference between genders for RPE for chest, $F(1, 28) = 2.66, p = .114$. The also was no significant difference in RPE for chest among grades, $F(2, 56) = 0.52, p = .600$. There was a significant difference found among resistances, $F(2, 56) = 15.52, p = .000$. A Tukey LSD post-hoc test indicated that significant differences existed between R4 and R12, and R8 and R12.
The ANOVA showed a significant interaction effect between resistance by gender, $F(2, 56) = 5.75, p = .005$. No other significant interaction effects were revealed.

For RPE for overall body, the ANOVA showed no significant difference between genders, $F(1, 28) = 3.91, p = .058$. There also was no significant difference among grades, $F(2, 56) = 2.78, p = .071$. The ANOVA did find a significant difference among resistances, $F(2, 56) = 23.55, p = .000$. A Tukey LSD post-hoc test indicated significant differences existed between R4 and R12, and R8 and R12. A significant interaction effect was found between resistance by gender, $F(2, 56) = 7.05, p = .002$. No other significant interaction effects were found.

Conclusions

From the results of this study, it was concluded that an increase in elliptical trainer grade and/or resistance level increased the workload and, therefore, increased the physiological demands of the exercise. Specifically, the results indicated that increasing the resistance increased workload more than increasing the grade at the same relative striding rate. It also was concluded that an increase in the resistance level increased the RPE of elliptical trainer exercise. An increase in grade resulted in an increased RPE for legs only.

In the study, the Precor® EFX™ 546 elliptical trainer provided a range of workloads based on the grade and resistance levels used. For that reason, the elliptical trainer is an appropriate exercise modality for beginning to intermediate exercisers.
Recommendations

The following are ideas for future research regarding elliptical trainer exercise:

1. Compare physiological and perceptual responses between forward and backward striding at various grade and resistance settings.

2. Compare physiological and perceptual responses at greater grades, resistance settings, and striding rates than used in the present study.

3. Examine biomechanical factors at various grade and resistance settings.

4. Measure electromyography activity of various muscles of the lower body at various grade and resistance settings.
Appendix A

Recruitment Script
Subject Recruitment Script

Drs. Dawson, Michael, and Zabik are in need of volunteers to participate in a research project that they are conducting titled Physiological and Biomechanical Assessment of Two Different Elliptical Trainers. The study will involve subjects between 18-35 years of age who are "low risk" according to ACSM's risk classification. Volunteers will complete a paper/pencil health risk appraisal form to qualify to participate in this study. Participation in this study involves one of the following:

1. Using the elliptical trainer with the moveable handlebars and with the stationary handlebars at a low, medium, and medium-high resistance settings (settings 5, 10, and 15 on the Precor Elliptical Trainers). Participation will involve four, 45-minute sessions.

2. Using the elliptical trainer at a low, medium, and medium-high resistance settings (settings 5, 10, and 15 on the Precor Elliptical Trainers) and at three grades; grade level, low, and medium (settings 5, 10, and 15 on the Precor Elliptical Trainers). Both a backward and forward cycling motion will be studied. Participation in this phase of the study will involve three, 45-minute sessions.

3. Exercising on the elliptical trainer as the workloads, every 3 minutes, becomes more difficult. The exercise session will stop when your heart rate gets to about 160 bpm (the average heart rate for more normal aerobic workouts). Your VO₂ max will also be measured. Participation in this phase of the study involved five sessions; two, 45-minute sessions to test VO₂ max and three, 30-minute sessions of a graded exercise tests using the elliptical trainer.

You have the option to voluntarily terminate your involvement in this study for any reason. Your participation during the study will not have any effect on your status as a student at Western Michigan University. All tests information will be kept confidential. If you are between the ages of 18-35 years of age, exercise 2-3 days per week, and are interested in getting more information of volunteering for the study, please print you name and phone number below or contact Dr. Dawson at 616 387-2546, Dr. Michael at 616 387-2691, or Dr. Zabik at 616 387-2542.

Thank you!

<table>
<thead>
<tr>
<th>Name</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B

Health Screening Form
Health Status Questionnaire

Instructions
Complete each question accurately. All information provided is confidential if you choose to submit this form to your fitness instructor.

Part 1. Information about the individual

1. 

2. 

3. 

4. 

5. 

6. Gender (circle one): Female Male (RF)

7. RF Date of birth: 

   Month Day Year

8. Number of hours worked per week: Less than 20 20-40 41-60 Over 60

9. SLA More than 25% of time spent on job (circle all that apply)

   Sitting at desk Lifting or carrying loads Standing Walking Driving

Part 2. Medical history

10. RF Circle any who died of heart attack before age 50:

    Father Mother Brother Sister Grandparent

11. Date of

    Last medical physical exam: 

    Year

    Last physical fitness test: 

    Year

12. Circle operations you have had:

    Back SLA Heart MC Kidney SLA Eyes SLA Joint SLA Neck SLA

    Ears SLA Hernia SLA Lung SLA Other
13. Please circle any of the following for which you have been diagnosed or treated by a physician or health professional:

<table>
<thead>
<tr>
<th>Condition</th>
<th>SEP</th>
<th>Condition</th>
<th>SEP</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcoholism</td>
<td></td>
<td>Diabetes</td>
<td></td>
<td>Kidney problem</td>
</tr>
<tr>
<td>Anemia, sickle cell</td>
<td></td>
<td>Emphysema</td>
<td></td>
<td>Mental illness</td>
</tr>
<tr>
<td>Anemia, other</td>
<td></td>
<td>Epilepsy</td>
<td></td>
<td>Neck strain</td>
</tr>
<tr>
<td>Asthma</td>
<td></td>
<td>Eye problems</td>
<td></td>
<td>Obesity</td>
</tr>
<tr>
<td>Back strain</td>
<td>SLA</td>
<td>Gout</td>
<td></td>
<td>Phlebitis</td>
</tr>
<tr>
<td>Bleeding trait</td>
<td>SEP</td>
<td>Hearing loss</td>
<td></td>
<td>Rheumatoid arthritis</td>
</tr>
<tr>
<td>Bronchitis, chronic</td>
<td>SEP</td>
<td>Heart problem</td>
<td></td>
<td>Stroke</td>
</tr>
<tr>
<td>Cancer</td>
<td>SEP</td>
<td>High blood pressure</td>
<td>RF</td>
<td>Thyroid problem</td>
</tr>
<tr>
<td>Cirrhosis, liver</td>
<td>MC</td>
<td>Hypoglycemia</td>
<td>SEP</td>
<td>Ulcer</td>
</tr>
<tr>
<td>Concussion</td>
<td>MC</td>
<td>Hyperlipidemia</td>
<td>RF</td>
<td>Other</td>
</tr>
<tr>
<td>Congenital defect</td>
<td>SEP</td>
<td>Infectious mononucleosis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

14. Circle all medicine taken in last 6 months:

<table>
<thead>
<tr>
<th>Medicine</th>
<th>SEP</th>
<th>Condition</th>
<th>SEP</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood thinner</td>
<td>MC</td>
<td>Epilepsy medication</td>
<td>SEP</td>
<td>Nitroglycerin</td>
</tr>
<tr>
<td>Diabetic</td>
<td>SEP</td>
<td>Heart rhythm medication</td>
<td>MC</td>
<td>Other</td>
</tr>
<tr>
<td>Digitalis</td>
<td>MC</td>
<td>High blood pressure medication</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Diuretic</td>
<td>MC</td>
<td>Insulin</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

15. Any of these health symptoms that occurs frequently is the basis for medical attention. Circle the number indicating how often you have each of the following:

<table>
<thead>
<tr>
<th>Symptom</th>
<th>MC</th>
<th>1 = Practically never</th>
<th>2 = Infrequently</th>
<th>3 = Sometimes</th>
<th>4 = Fairly often</th>
<th>5 = Very often</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Cough up blood</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Abdominal pain</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Low-back pain</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Leg pain</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Arm or shoulder pain</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. Chest pain RF</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. Swollen joints</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. Feel faint</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. Dizziness</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>j. Breathless with slight exertion</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>k. Palpitation or fast heart beat</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l. Unusual fatigue with normal activity</td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part 3. Health-related behavior

16. RF Do you now smoke? Yes No

17. RF If you are a smoker, indicate number smoked per day:

<table>
<thead>
<tr>
<th>Cigarettes:</th>
<th>40 or more</th>
<th>20-39</th>
<th>10-19</th>
<th>1-9</th>
<th>Less than 5, none inhaled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cigars or pipes only:</td>
<td>5 or more or any inhaled</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
18. **RF** Do you exercise regularly?  
   Yes   No

19. How many days per week do you accumulate 30 minutes of moderate activity?  
   0 1 2 3 4 5 6 7 days per week

20. How many days per week do you normally spend at least 20 minutes in vigorous exercise?  
   0 1 2 3 4 5 6 7 days per week

21. Can you walk 4 miles briskly without fatigue?  
   Yes   No

22. Can you jog 3 miles continuously at a moderate pace without discomfort?  
   Yes   No

23. Weight now: ________ lb.  
   One year ago: ________ lb.  
   Age 21: ________ lb.

**Part 4. Health-related attitudes**

24. **RF** These are traits that have been associated with coronary-prone behavior. Circle the number that corresponds to how you feel:
   
   6 = Strongly agree  
   5 = Moderately agree  
   4 = Slightly agree  
   3 = Slightly disagree  
   2 = Moderately disagree  
   1 = Strongly disagree

I am an impatient, time-conscious, hard-driving individual.

1 2 3 4 5 6

25. List everything not already included on this questionnaire that might cause you problems in a fitness test or fitness program:

**Code for Health Status Questionnaire**

The following code will help you evaluate the information in the Health Status Questionnaire.

EI = Emergency Information—must be readily available.
MC = Medical Clearance needed—do not allow exercise without physician’s permission.
SEP = Special Emergency Procedures needed—do not let participant exercise alone; make sure the person’s exercise partner knows what to do in case of an emergency.
RF = Risk Factor for CHD (educational materials and workshops needed).
SLA = Special or Limited Activities may be needed—you may need to include or exclude specific exercises.
OTHER (not marked) = Personal information that may be helpful for files or research.
Appendix C

Human Subjects Institutional Review Board
Letter of Approval
To: Mary Dawson, Principal Investigator
Roger Zabik, Co-Principal Investigator
Tim Michael, Co-Principal Investigator
Erica McManus, Student Investigator as faculty assistant
Katherine Wehmeyer, Student Investigator as faculty assistant

From: Sylvia Culp, Chair

Re: HSIRB Project Number: 00-10-05

This letter will serve as confirmation that your research project entitled "Physiological and Biomechanical Assessment of Two Different Elliptical Trainers" has been approved under the expedited category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: 20 October 2001
Appendix D

Consent Form
Western Michigan University
Department of Health, Physical Education, and Recreation
Principal Investigators: Drs. Mary Dawson, Tim Michael, and Roger Zabik
Student Investigators: Katherine Wehmeyer and Erica McManus

I have been invited to participate in a research project that will study the physiological and biomechanical effect of exercise when using an elliptical trainer. The research will describe the alignment of the lower extremities during a complete cycle of motion, the cardiopulmonary (heart and lungs) efficiency at various grades and elevations, and my perceived exertion. I will exercise on one Precor elliptical trainer, the EFX 546 or the EFX 556. The research project in which I am involved is part of a project conducted by Drs. Dawson, Michael, Zabik, and students (Katherine Wehmeyer and Erica McManus) and will be conducted in the Exercise Physiology and Biomechanics Laboratory in the Department of Health, Physical Education and Recreation in the Student Recreation Building at Western Michigan University. The extent of my participation involves the paragraph(s) checked below. I will not be involved in those paragraphs that are not checked.

☐ My consent to participate in this project indicates that I will be asked to attend four, 45-minute sessions. I will meet the researchers in the Student Recreation Building, Rooms 1050-60, Western Michigan University. These sessions will begin with a 10-15 minute period in which I will be allowed to warm up using my personal pre-exercise workout. During each of the four sessions I will complete one of the following exercise conditions on the elliptical trainer EFX 556: (1) Arms on moveable handles, legs move forward; (2) Arms on moveable handles, legs move backward; (3) Arms on stationary handles, legs move forward; and (4) Arms on stationary handles, legs move backward. During each session, I will exercise in the manner described above for a 5-6 minute period at a prescribed resistance level. I will then stop and rest until my heart rate is below 100 bpm. After resting, I will repeat this procedure for two different resistance levels.

☑ My consent to participate in this project indicates that I will be asked to attend three, 45-minute sessions. I will meet the researchers in the Student Recreation Building, Rooms 1050-60, Western Michigan University. The sessions will begin with a 10-15 minute period in which I will be allowed to warm up using my personal pre-exercise workout. During each of the three sessions I will complete one of the following exercise conditions on the elliptical trainer EFX 546: (1) 5% elevation, (2) 10% elevation, and (3) 15% elevation. During each session, I will exercise in the manner described above for a 5-6 minute period at a prescribed resistance level. I will then stop and rest until my heart rate is below 100 bpm. After resting, I will repeat this procedure for two different resistance levels.
My consent to participate in this project indicates that I will be asked to attend two, 45 minute sessions. I will meet the researchers in the Student Recreation Building, Rooms 1050-60, Western Michigan University. These sessions will begin with a 10-15 minute period in which I will be allowed to warm up using my personal pre-exercise workout. During each of the two sessions I will be administered a test that measures my cardiopulmonary (heart and lungs) limits. For this test, I will run on a treadmill with the speed and uphill grade increasing until I decide I can not continue or until the investigators decide that I should stop.

During my participation on the elliptical trainer, I will breathe through a mouth piece like a swimming snorkel. To assure that I am breathing only through my mouth, I will wear nose clips. My heart rate will be monitored by wearing an adjustable elastic band with build in electrodes around my rib cage just below the breast bone. The elastic band will be under my exercise shirt. My heart rate will be recorded on a display that I will wear on my wrist like a watch.

During my participation on the elliptical trainer my performance will be video taped so that the researchers can measure the joint angles in my lower legs during selected parts of the cyclic motion.

At the end of my first session as a subject, I will be asked to run on a treadmill at the same rate (stepping rate) that I performed on the elliptical trainer. During the time I am running, I will be video taped.

Prior to my participation EMG electrodes will be placed over the following muscles in my lower extremities: Front of thighs, back of thighs, back of calf, and front of calf. The site of the electrode placement will be scrubbed vigorously with a sterile alcohol pad and may be shaved to provide a better electrode contact surface.

The current testing may be of no benefit to me. Knowledge of how the body reacts to Precor elliptical trainers may help fitness specialists in who should and should not use the trainers and aid the company in design changes in future models of Precor trainers.

As in all research, there may be unforeseen risks to the participant. The risks to the research participant in this study include risks taken in any moderate exercise program for normal healthy individuals including those using an elliptical trainer. Risk include abnormal blood pressure, fainting, irregular, fast or slow heart rhythm, and in rare instances, heart attack, stroke, or death. A person trained in first aid and CPR will be present during the exercise sessions. If an emergency arises, appropriate immediate care will be provided and I will be referred to the Sindecuse Health Center. No compensation or treatment will be made available to me except as otherwise specified.
compensation or treatment will be made available to me except as otherwise specified in this consent form.

All information concerning my participation is confidential. This means that my name will not appear in any document related to this study. The forms will all be coded. Dr. Dawson will keep a separate master list with the names of all participants and their code numbers. Once the data are collected and analyzed, the master list will be destroyed. The consent and data forms, a disk copy of the electronic generated data, and the video tapes will be retained for a minimum of 3 years in a locked file in the principal investigator’s laboratory. A second disk copy of the electronic data will be stored by Dr. Michael for a minimum of 3 years.

I may refuse to participate or stop at any time during the study without any effect on my grades or relationship with Western Michigan University. If I have any questions or concerns about this study, I may contact Dr. Mary Dawson at (616) 387-2546, Dr. Timothy Michael at (616) 387-2691, or Dr. Roger Zabik at (616) 387-2542. I may also contact the Chair of Human Subjects Review Board at (616) 387-8293 or the Vice President for Research at (616) 387-8928 with any concern that I have.

My signature below indicates that I am aware of the purpose and requirements of the study and that I agree to participate.

This consent document has been approved for 1 year by the Human Subjects Institutional Review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right hand corner of all pages of this consent form. Subjects should not sign this if the corners do not show a stamped date and signature.

______________________________________________________________
Signature of Participant                                         Date

______________________________________________________________
Signature of Investigator Obtaining Consent                       Date
Appendix E

Bruce Protocol
## The Bruce Treadmill Graded Exercise Protocol

<table>
<thead>
<tr>
<th>% Grade</th>
<th>Time (min)</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.7 mph</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2.5 mph</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>3.4 mph</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>4.2 mph</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>5.0 mph</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>5.5 mph</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BIBLIOGRAPHY


