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Comparing energy expenditure between the treadmill and elliptical trainer

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COMPARING ENERGY EXPENDITURE BETWEEN THE TREADMILL AND ELLIPTICAL TRAINER

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by

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

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ABSTRACT

The elliptical trainer (ET) is a relatively new exercise device that is gaining popularity. Despite popularity, the ET has received little research attention, especially in comparison to other modalities. The purpose of this study was to compare physiological responses during ET and treadmill (TM) exercise at three intensities gauged using RPE. Twenty-four physically active males (n = 12) and females (n = 12) completed maximal and submaximal exercise sessions on both modalities. Maximal tests were used to obtain mode specific VO_{2max}, HR_{max} and RPE_{max}. The submaximal exercise sessions, which followed 48 h after maximal testing, consisted of three 6-min exercise bouts at RPE-gauged intensities of 11 (fairly light), 13 (somewhat hard) and 15 (hard) on each modality. Each subject's RPE intensity order was pre-assigned in a partially randomized, balanced order. Three 2 x 2 ANOVAs comparing mode and gender for the dependent variables VO_{2max}, HR_{max}, and RPE_{max} showed TM elicited a greater VO_{2max} and HR_{max} than ET ($p < 0.05$). Submaximal exercise data were analyzed using 2 x 2 x 3 ANOVAs comparing mode, gender and RPE intensity level. Analysis revealed that TM elicited greater submaximal VO_2, HR and energy expenditure (EE) than ET across the three RPE-gauged intensities ($p < 0.05$). There were no modality-related gender differences observed. The results of this study demonstrated that TM produces greater EE than ET with less strain or feeling of exertion. Movement patterns associated with ET may elicit localized leg fatigue that affects perception of intensity thereby leading to lower EE at a given RPE. Despite EE differences, ET provides a respectable, low-impact exercise alternative to TM running. If maximizing EE with the lowest perception of effort is the goal, however, then TM is the recommended modality. Exercise prescriptions using RPE should consider this information when switching between modalities.

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DEDICATION

This thesis is dedicated to the loving memory of Suzanne Elizabeth Clark, who taught me to fully appreciate and embrace each and every day.
I will miss you always

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Chapter 1

INTRODUCTION

Every few years an exercise equipment manufacturer tries to capture a share of the equipment market with a new exercise machine. One of the more popular recent machines is the elliptical trainer, which is a cross between a stationary upright cycle and a stepper with the feel of a treadmill. Similar to the bike and stepper, the motion is a closed chain exercise with minimal impact forces on the feet (Porcari, Foster, & Schneider, 2000). The motion of the lower body resembles an elliptical shape, somewhat like a normal walking or running stride. Although the elliptical trainer is extremely popular in health clubs, it is not well researched.

With so many equipment options for cardiovascular exercise, is one the best? The answer depends on the goals and limitations of the person exercising. The Surgeon General recommends at least 20 minutes of moderate exercise most days of the week for cardiovascular benefits (ACSM, 2000). Most available exercise modalities can provide this moderate exercise prescription, however some exercise machines may elicit a more productive workout than others (Berry, Weyrich, Robergs, Krause, & Ingalis, 1989; Ceci & Hassmen, 1991; Dunbar et al., 1992; Dunbar, Goris, Michielli, & Kalinski, 1994; Hetzler, Seip, Boutcher, Pierce, Snead, & Weltman, 1991; Kravitz, Robergs, Heyward, Wagner, & Powers, 1997; Porcari et al., 2000; Robertson et al., 1990; Thomas, Feiock, & Araujo, 1989). Therefore, it may be advantageous to use one machine rather than another to produce a greater exercise response with less perceived effort. In this regard, the elliptical trainer has not been examined.

Although there is no one gold standard for exercise response, heart rate (HR), percent of maximal oxygen consumption (VO_{2max}), ratings of perceived exertion (RPE), and energy expenditure (EE) each provide an estimate of the intensity of exercise. The RPE scale is a means of gauging subjective feelings of exertion by use of a categorical scale. The scale measures the intensity of effort, strain, discomfort, and fatigue during exercise. RPE is widely used in the fitness industry and during cardiac rehabilitation as a guide for cardiovascular exercise intensity. Exercise RPE compares favorable to HR and percent VO_{2max} as an indicator of exercise intensity (Dishman, 1994; Dishman, Patton, Smith, Weinberg, & Jackson, 1987; Eston, Davies, & Williams, 1987; Feriche, Chicharro, Vaquero, Perez & Lucia, 1998; Glass, Knowlton, & Becque, 1992). RPE is also a convenient way to maintain a prescribed exercise intensity because of its simplicity and cost effectiveness. Although HR is more commonly used to monitor intensity, it is sometimes difficult to measure without a monitor. Measurement of HR by palpitation also usually requires cessation of activity (Dishman et al., 1994). Use of submaximal VO_2 and EE require expensive equipment and are not considered a practical way of gauging intensity.

Since RPE is a simple measure of effort during exercise, the question of interest becomes, which cardiovascular machine allows individuals to maintain the lowest RPE while expending the most calories? Monya et al. (2001) addressed this issue by comparing the EE on the treadmill, ski simulator, stair-stepper, rowing ergometer, aerobic rider, and cycle ergometer while subjects exercised at three intensities gauged by RPE. These authors found large differences in EE between each of the machines with the treadmill and the ski simulator showing the highest EE at a specified RPE. Kravitz et al. (1997) and Zeni et al. (1996) also performed similar comparative studies of multiple exercise modalities and found the treadmill produced the highest EE. The popular stationary bike finished near the bottom in terms of EE for all three studies. In practical terms, Moyna et al. stated that it would take 30 minutes on a stationary bike and only 15 minutes on a treadmill to burn 200 kcals at a moderate RPE intensity. This difference in time could be of importance to an exercising individual with a goal of weight loss. The elliptical trainer, however, was not examined in any of these studies. Since the elliptical trainer is a popular form of exercise, it is important to determine how it compares to the treadmill.

Purpose

The purpose of this study was to compare the treadmill and the elliptical trainer in terms of physiological response at three intensities gauged using RPE values.

Null Hypothesis

The hypothesis was that there would be no difference in EE, submaximal VO_2 or submaximal HR between the treadmill and elliptical trainer at any of the three selected RPE intensity levels.

Assumptions

- The graded exercise test (GXT) protocols used produced good indications of VO_{2max}, especially for the elliptical trainer.
- Subjects were able to accurately produce the given RPE based on their GXT experience.
- Elliptical trainer resistance settings increase in a linear fashion, so that the change in resistance is consistent throughout all machine levels.

- Subjects did not become fatigued during the three submaximal trials and therefore fatigue did not impact performance.

Definition of Terms

- Physically active – a subject who has performed at least 90 minutes of moderate aerobic exercise per week for the previous four months.
- RPE scale – a 15 point scale (Borg, 1982) that subjectively measures exercise intensity.
- Stride (on elliptical trainer) –with one foot forward and one foot back to start, a stride is completed when you move the rear foot all the way forward while the forward foot moves to the rear (Precor, 1999).
- Cadence (on elliptical trainer) – the number of strides per minute.

Delimitations

- Subjects were between the age of 18 and 29 years of age.
- The subjects had previously exercised on a consistent basis and were considered physically active.
- The subjects had at least ten exercise sessions on both the treadmill and elliptical trainer to ensure a learning curve did not affect results.
- For each individual subject the maximal and submaximal trials were performed the same time of day to minimize daily variation in variables of interest.
- A questionnaire was used to examine a possible bias that could affect the results, specifically the interpretation of the RPE scale on each machine.

Limitations

- The results of study may not apply to people over the age of 30 and under the age of 18.
- The results may not apply to people without previous experience on both modalities. Someone who initially exercises on the treadmill or elliptical trainer may perceive it harder at first.
- The results may not apply to people exercising at different times of the day. It has been shown that exercising in the morning or evening may affect the rate of EE.
- Physically inactive sedentary people may produce different results. The subjects in this study were considered physically active. Sedentary people may perceive the exercise on each machine differently than those that are physically active.
- The results may not apply if the treadmill and elliptical trainer are located in separate areas. It is possible for location of exercise machine to affect perception of exercise intensity.
- A person's bias toward one machine may affect the results, specifically the interpretation of the exercise intensity. Someone who enjoys running may find the treadmill much easier than someone who does not enjoy running.

Chapter 2

REVIEW OF LITERATURE

When comparing the treadmill and elliptical trainer, it is important to examine previous research related to the topic. There is limited research on the elliptical trainer, but there are important related studies in which the similarities and differences of other exercise modalities, such as the treadmill, stepper, stationary bike, and cross-country ski machine are examined. Since RPE is a key component to this study, it is also important to review the research that used RPE to prescribe exercise intensity. Therefore, this chapter will review 1) Cardiovascular exercise and caloric expenditure, 2) Elliptical trainer research, 3) Comparison of EE for different exercise modalities, and 4) RPE and exercise prescription.

Cardiovascular Exercise and Caloric Expenditure

In simplest terms, exercise and physical activity burn calories, which contributes to healthy weight management. Although exercise may decrease appetite while increasing lean body mass and basal metabolic rate, the calories expended garners the most attention when weight management is considered (Grilo, 1995). A calorie deficit of 3500 calories leads to the loss of one-pound of body fat (ACSM). The healthiest way to achieve a caloric deficit is to eat properly and exercise regularly. A good cardiovascular exercise regimen incorporates a consistent frequency, intensity, and duration. The average workout session burns about 200 – 500 calories (Moyna et al., 2001). For example, a 175 pound man jogging at 7.5 mph for 20 minutes burns about 300 kcals. An increase in speed (intensity) or duration will increase his caloric expenditure. Since it is difficult to accumulate a 3500 kcal deficit in one day, most people must exercise several days a week.

Caloric expenditure is typically measured with indirect calorimetry, which uses VO_2 to estimate the energy cost of the activity. A metabolic cart is commonly used to measure VO_2, and therefore, to determine caloric expenditure. To increase the accuracy of indirect calorimetry, the exercise session must be cardiovascular and steady state. The respiratory exchange ratio (RER) is also determined during the exercise session. The RER is used to estimate the respiratory quotient (RQ) and calculate what substrates are utilized during exercise. The range for RER is between 0.7 and 1.0; a value close to 0.7 reflects fat oxidation, whereas a value close 1.0 indicates carbohydrate oxidation (McCardle et al., 2000).

The use of a metabolic cart to measure caloric expenditure is not always feasible so equations and charts are used instead. Equations and charts are easy and convenient, but they only apply to certain age groups or body weight ranges. In addition to charts and equations, a person may rely on the caloric expenditure value given on an exercise machine. Many commercial machines (including the treadmill and elliptical trainer) require the user to enter body weight, which increases the accuracy of the calculation relative to machines that do not require weight input (Clay, 2000).

Elliptical Trainer Research

Throughout the past decade, the elliptical trainer has been modified to better suite the needs of the consumer. Currently, there is a variety of makes and models of the machine, which range in price and quality. In his work with elliptical trainers, Kravitz (1998) surveyed opinion on a variety of models and found that the Ellipse by Norditrack was the highest rated, followed by the HealthRider Elliptical Crosstrainer by ICON Health and Fitness, the

Powertrain by Gunthy-Renker, and the Cyclone Crosstrainer by Quantum Television. All the aforementioned machines are home models as opposed to the commercial models typically found in health clubs. Commercial models are rated higher then home models (Kuntzleman, 1998). The two highest ranked commercial models were the Reebok Personal Trek and Precor EFX (Consumer Reports, 1998). These two machines cost about $4500, whereas the home models cost between $500 and $1000. The Precor EFX, the highest rated elliptical trainer, was used in the present study (Kuntzleman, 1998).

A crucial difference between models is the handlebars. Some models have moveable handlebars, similar to a ski simulator, that provide an upper body workout. In contrast, other models, such as the Precor EFX 546, have fixed handlebars used only for balance. Precor (2001) stated that models such as their EFX 556, which have movable handlebars, provide added resistance during the workout, thereby increasing EE. There is no indisputable research to support this statement, but adding upper body work (such as hand weights) to cardiovascular exercise increases EE (Kravitz, Heywardm, Stolarczyk, & Wilmerding, 1997; Owens, Al-Ahmed, & Moffatt, 1989; Porcari, Hendrickson, Walter, Terry, & Walsko, 1997).

Even though the elliptical trainer has been around for well over a decade, the physiological responses to exercise on it are not well documented. In all, there have been four studies that have looked at the elliptical trainer, but it is difficult to fully compare these data because of methodological differences. Mercer et al. (2001) compared the maximum physiological response to elliptical trainer and treadmill exercise, specifically examining VO_{2max}, HR_{max}, and RPE_{max}. No significant differences were found; hence, the elliptical trainer elicited a similar maximum exercise response as the treadmill. Next, the authors designed a GXT protocol for the elliptical trainer in which cadence and resistance were used to manipulate intensity. It was found that HR and VO_2 increased linearly, similar to a treadmill GXT. Therefore, the elliptical trainer can be used for a GXT, a factor critical to the design of this study.

Porcari et al. (2000) compared the physiological responses and vertical ground reaction forces from the elliptical trainer, treadmill (walking and running), stationary bike, and stepper. Subjects completed a 20 min bout of exercise on each machine at a self-selected pace that was similar to the subject's typical workout intensity. There was no difference in submaximal HR and VO_2 between the treadmill (running) and elliptical trainer, although these responses were significantly higher than those elicited on the stationary bike, stepper, and treadmill while walking. Despite some differences in HR and VO_2, RPE values were similar (12.8 ± 1.1) for all modalities. These data suggest that similar RPE responses may evoke different submaximal HR and VO_2 values. It was also found that treadmill ground reaction forces were almost 2.5 times greater than those associated with the elliptical trainer, verifying the main selling point of the machine; namely, it's low impact relative to the treadmill. There was no difference in ground reaction forces among the elliptical trainer, stationary bike, and stepper.

A similarly study was conducted by Kim (1999), who compared the elliptical trainer, treadmill, cycle ergometer, and Airdyne dual action cycle. Twelve obese men and women completed 15-minute trials at a prescribed RPE of 11-12. The elliptical trainer elicited the highest EE (8.0 ± 2.0 kcal/min), followed by the treadmill (6.6 ± 2.1 kcal/min), the Airdyne (6.3 ± 2.0 kcal/min), and the cycle ergometer (5.3 ± 2.1 kcal/min).

Spranger (1998) compared submaximal VO_2, HR, RER, RPE, caloric expenditure, and O_2 pulse responses for subjects that exercised on the elliptical trainer, ski simulator, non-motorized treadmill, and Airdyne dual action cycle. Subjects were asked to exercise at a moderate intensity, one that reflected an intensity used for an average workout session. The elliptical trainer and treadmill (although non-motorized) elicited a similar response, which was greater than the response for other the modalities. In contrast to previously described studies, this study used a non-motorized treadmill; it is unknown how this type of treadmill compares to a motorized one.

The work of Porcari et al. (2000) and Spranger et al. (1998) showed that the elliptical trainer elicits similar EEs as a treadmill, whether motorized or non-motorized, and a greater EE than other exercise machines. Data from Kim (1999) agreed largely with the aforementioned data, although he found that the elliptical trainer elicited a greater EE than the treadmill. Unstandardized methods between Pocari et al. (2000), Spranger et al. (1998) and Kim (1999) may account for differences in results and need to be addressed in future studies. Different makes and models of elliptical trainers were used in the aforementioned studies, which could have affected the perception of exercise intensity. For example, Porcari et al. (2000) used a Norditrack Ellipse, Kim (1999) a Body Trec arm/leg elliptical trainer and Spranger (1998) does not mention the make and model of elliptical trainer used. In short, the various models have different feels (Consumer Reports, 1998; Kravitz et al., 1998). Some of these machines, for example, ride different than others, whereas treadmills do not show much variability among makes and models. There is no mention of what the "feel of" the machine refers to, but it is probably related to the shape of the ellipse made by the machine.

Another potential methodological shortcoming is the direction of ellipse, as the user can either move forward or backward. The manufacturers state that going backwards works different muscles and possibly burns more calories (Precor, 2001). This could have affected study outcomes because Bakken (1998) found that going backward burned 7 % more calories than going forward. Kim (1999) and Spranger (1997) do not mention whether their subjects went forward or backward. Going backward possibly provides a different workout, and a study using an electromyography (EMG) would uncover more information about this topic (Porcari et al., 2000).

Another methodological inconsistency concerns upper body movement. The use of movable upper body handlebars versus stationary ones may alter perceived exercise intensity. In addition, users of the elliptical trainer with stationary handlebars also have the option to either hold on or pump their arms while exercising. Kim (1999) used an elliptical trainer model that had a movable upper component whereas Spranger et al. (1998) and Porcari (2000) do not mention whether their elliptical trainer model featured the movable upper body component. Since the position of the subject's hands was not discussed in the three studies, it is difficult to compare the data.

Another unstandardized methodological factor is the prescription of exercise intensity. Subjects in Porcari et al. (2000) and Spranger et al. (1998) exercised at a moderate intensity, one that reflected an intensity used for an average workout session, whereas Kim (1999) used the RPE scale to prescribe intensity. Since RPE is a more objective measure of intensity than the one used by Porcari et al., it may have allowed for a more consistent intensity among the machines.

A final unstandardized area was subject fitness and experience level with the machines. Kim (1999) used obese men and women for example, and found the elliptical trainer elicited the greatest EE. Spranger et al. (1998) and Porcari et al. (2000), both of whom found no difference between the treadmill and elliptical trainer, did not specify the weight of their subjects. An obese person may find the impact of the elliptical trainer more comfortable then the treadmill, thereby lowering perceived exertion of the given intensity. In short the elliptical trainer may have felt better, allowing subjects to exercise more vigorously at the same RPE, which may account for Kim's finding that the two modalities elicited similar EE. Previous exercise experience on the machine also could have affected the results of these studies. For example, a person who is a novice with the elliptical trainer may perceive a greater intensity than someone who has no previous experience.

The various methods associated with the aforementioned studies make it difficult to draw a general conclusion about the performance of the elliptical trainer compared to other exercise machines. The present study addresses many of these issues; it eliminates the upper body use in the elliptical trainer by using a model with stationary handle bars; it uses RPE to gauge intensity; and uses physically active subjects who have had prior exercise experience with both machines. These standards should improve upon the methods used in the aforementioned studies.

Comparison of Energy Expenditure for Different Exercise Modalities

In contrast to the small quantity of studies that have examined the elliptical trainer, many researchers have compared the EE of other modalities, such as the treadmill and cycle ergometer. The purpose of these studies was to find the exercise modality that provides the most effective workout with the least amount of perceived effort. The methods of these studies are similar to those of the present study.

Moyna et al. (2001), Kravitz et al. (1997), and Zeni et al. (1996) compared the rates of EE, VO_2, and HR for subjects who used the treadmill, stepper, cycle ergometer, rowing ergometer, cross-country ski simulator, aerobic rider, and Airdyne dual action cycle. Two of the studies also looked at gender differences in physiological response to each modality. Moyna et al. (2001) and Zeni et al. (1996) gauged exercise intensity using three commonly prescribed RPE values (11, 13, and 15), whereas Kravitz et al. (1997) used a self-selected pace that was similar to the subject's typical workout intensity. Although RPE represents a subjective feeling of exercise, Kravitz et al. (1997) stated that they did not want to overly interfere with the typical exercise experience of the subjects.

Moyna et al. (2001) found that subjects burned the same amount of calories on the treadmill and ski simulator at all three intensities, followed by the rowing ergometer, stepper, aerobic rider, and cycle ergometer. Kravitz et al. (1997) and Zeni et al. (1996) found only the treadmill produced a significantly greater EE compared to the other modalities. All three studies also showed that the aerobic rider and the cycle ergometer induced the lowest rates of EE. Collectively, data from these studies show that there are large differences in EE among exercise machines at selected RPE. A practical example of this difference was illustrated by Moyna et al. (2001), who stated that a male exercising at a moderate intensity (RPE 13) would have to exercise for 30 min to burn 200 kcals on the cycle ergometer, whereas it would only take 15 min to burn those calories on the treadmill.

Similarly, there were gender differences in EE and submaximal VO_2 across all modalities at the same RPE, as males expended more energy and had a higher submaximal VO_2 compared to females at each intensity (Kravitz et al., 1997; Moyna et al., 2001). This was expected due to differences in body size and body composition. In contrast to the differences in the EE and submaximal VO_2, the gender difference in submaximal HR varied among the studies. Kravitz et al. (1997) showed that females had a higher submaximal HR at each intensity on all modalities than males, an expected outcome based on difference in body size. Data from Moyna et al. (2001), however, did not corroborate this finding, with some RPE levels eliciting a higher HR in males and other RPE levels eliciting a higher HR in females.

The results for gender EE among the modalities differed in the studies. Kravitz et al. (1997) and Zeni et al. (1996), for example, found no difference in EE between genders among the exercise modalities. In contrast, Moyna et al. (2001) found that females burned similar quantities of calories on the rowing ergometer, treadmill, and ski simulator, whereas males burned fewer calories on the rower ergometer compared to the treadmill and ski simulator.

These data did not support the theory that machines that exercise both the upper and lower body, such as rowing ergometer, cross country ski machines, rowing ergometer, and the Airdyne dual action cycle elicit higher EE at any given perceived exertion (Kravitz et al., 1997; Moyna et al., 2001;). Indeed the majority of data show that the treadmill elicited the greatest EE at any given RPE (Kravitz et al., 1997; Zeni et al., 1996), or a similar EE to a ski simulator but greater than the other arm and leg exercisers (Moyna et al., 2001). The only exception was that in one study the rower and ski simulator elicited greater EE than the other modalities, but only in females, a gender specific response (Moyna et al., 2001).

In short, the addition of arm work to leg work may decrease the contribution of the larger leg muscles, thereby negating the addition of arm work (Kravitz et al., 1997; Zeni et al., 1996). Also, the upper body muscles tend to have a lower aerobic capacity than the lower body muscles, therefore increasing the perception of intensity; hence, the ski simulator and aerobic rider elicit a lower submaximal VO_2 value compared to the treadmill at any given RPE.

This difference in perceived exertion may be due to an elevated blood lactate concentration (BLC) as BLC was similar across all modalities except for the ski simulator, where it was higher (Zeni et al., 1996). In short, BLC may affect RPE, which in turn affects EE, submaximal HR and VO_2. Indeed the correlation between BLC and RPE is strong as shown by Hetzler et al. (1991), who found that treadmill exercise and cycle ergometry elicited different submaximal HR and VO_2 at different workloads, which was set at fixed BLC of 2.0, 2.5 and 4.0 mmol. In contrast, RPE was similar at this fixed BLC across the two exercise modalities. Hence, if the combined exercise machines required unaccustomed movement patterns with an unfamiliar exercise, one that required more work from a smaller muscle group (arms versus legs), then such exercise may elicit a higher lactate and RPE response at any given HR or VO_2. .

In all, factors such as the movement patterns of the exercise, the degree to which eccentric and isometric contractions are involved and the familiarity with the exercise may partially account for why the combined exercise did not elicit greater EE then single muscle group exercise (Zeni et al., 1996). Ultimately the size of the exercising muscle mass may be the reason why there is a greater metabolic demand during treadmill running compared to exercise on other modalities.

In closing this section, it is important to recall that choosing a machine that expends the most calories with the least amount of perceived effort is important for weight management. Data show that the treadmill consistently produces the highest caloric expenditure at any given RPE compared to other modalities. Reasons for the differences EE among the modalities includes the quantity of exercising muscle, type of movement, and the blood lactate response. Although the elliptical trainer is a popular form of aerobic exercise, it was not utilized in any of these studies.

RPE and Exercise Prescription

The use of RPE to produce desired exercise intensity has been thoroughly researched, and it is endorsed by the American College of Sports Medicine (ACSM, 2000). As such, it is commonly used in health clubs and cardiac rehabilitation clinics. However, the more common method of gauging exercise intensity is with HR. Using HR to gauge intensity seems better because it relies on an objective measure rather than a subjective perceptual feeling. However, Dishman (1994) discussed three major weakness associated with using HR to regulate intensity. First, when variability due to age, training status, and testing mode is accounted for, the standard deviation of an obtained HR_{max} is about 11 bpm. This variability in HR_{max} may allow for an inaccurate prescription of intensity. Secondly, HR can be affected by emotional status, medications, and inaccuracy in self-monitoring (Dishman, 1994). The latter issue is compounded if the person does not have a HR monitor, as measuring HR pulse is difficult and usually requires cessation of activity. Also if the pulse is only measured for 10 s as opposed to 60 s, as it commonly is, there is an increased chance that the rate measured is off by +/- 12 bpm (Dunbar et al., 1994).

Morgan (1981) and Noble (1982) reported that RPE may better estimate VO_2 than HR, and HR and RPE together could be more accurate than either alone. Since use of the RPE scale is a convenient way to monitor and prescribe exercise intensity, it is important to examine the reliability and accuracy of RPE. For the present study and some of the previously mentioned studies, the accuracy of RPE prescription was crucial to the results. In a study by Eston et al. (1987), the accuracy of RPE production from a GXT is examined at three RPE values (9, 11, 17). The subjects had a GXT, followed by the three RPE production trials on a treadmill. The results supported the idea that using the RPE scale is a valid way to regulate exercise intensity based on one GXT learning session. The intensity produced from a RPE of 13 fell between the ACSM recommended intensity 50-85% VO_{2max} and had the strongest correlation with the GXT. This is supported by Dishman (1994), who stated that RPE production is most accurate between 50% and 70% of VO_{2max}. Glass et al. (1992), utilizing similar methods as Eston et al.(1987), showed that RPE values from a single GXT could accurately be used to prescribe a desired intensity. The subjects were asked to adjust the speed of the treadmill to a prescribed RPE that was equivalent to 75% of their HR reserve (from GXT). There was no significant difference in submaximal HR, VO_2, and V_E between the GXT and the submaximal exercise test. At 75% of HR reserve, the average prescribed RPE was 12, which supports the research by Dishman that this middle intensity range is most accurate for RPE exercise prescription. Reproducing an intensity gauged by RPE from a single GXT experience was crucial to the methodology of the present study.

The present study utilized the RPE scale in both measuring and prescribing exercise intensity. The validity and accuracy of the RPE scale was crucial to the present study; hence it is important to examine the current research on this topic. Much of the research does show that the RPE is a valid scale, and can be used for exercise prescription after just one GXT experience.

Summary

EE is an important consequence of cardiovascular exercise as it helps in weight management. There are many types of cardiovascular exercise, including the popular elliptical trainer. Currently there is little research comparing the elliptical trainer to other modalities. Although the elliptical trainer does produce similar physiological effects as the treadmill, the research is inconsistent in terms of type of elliptical trainer used and method of prescribing exercise intensity. Hence, the rationale for this study is to compare elliptical trainer to the treadmill at three exercise intensities gauged by RPE using methods similar to Moyna et al. (2001), Kravitz et al. (1997) and Zeni et al. (1996). By using these methods, it allows for indirect comparison to other researched modalities besides the treadmill.

Chapter 3

METHODS

This study was done to assess EE on the treadmill and elliptical trainer at three given intensities. Subjects completed four days of testing: two treadmill trials and two elliptical trainer trials. One trial for each modality was a maximal exercise session, whereas the other trial was a submaximal exercise session. Each session was separated by at least two days. The treadmill and elliptical trainer trials were separated by at least one week. This chapter describes the methods of this study, including: 1) Subjects; 2) Preliminary Group Meetings; 3) Procedure; and 4) Statistical Analysis.

Subjects

Twenty-four healthy men (n = 12) and women (n = 12) volunteered for this study. The number of subjects was deemed adequate because Monya et al. (2001) used only 19 subjects to find significant results with a similarly designed study. Subjects were between 18 and 29 years of age and were physically active as defined by performing ≥ 90 minutes of moderate aerobic exercise per week for a minimum of the last four months prior to this study. To qualify for this study subjects also were required to have previous experience of at least ten workout sessions on the treadmill and ten on the elliptical trainer. Monya et al. (2001) had subjects participate in four practice sessions before testing, but it was deemed that subjects' in the present study had previous exercise experience on each modality that was sufficient. In an initial interview with each potential subject, he or she reported if the stated requirements for physical activity experience were met.

Preliminary Group Meetings

At a preliminary group meeting, the experimenter met with the subjects to explain the testing procedure. At this time, the subjects completed a PAR – Q (physical activity readiness questionnaire) (Appendix A) and signed the informed consent (Appendix B). Subjects also completed an exercise preference questionnaire, which had them rate various exercise modalities (Appendix C). The RPE scale was introduced to the subjects and questions were answered.

Procedure

The treadmill and elliptical trainer trials consisted of two parts: a maximal and a submaximal exercise session. The maximal sessions functioned not only as a baseline measurement, but also as a tutorial for the RPE scale before use in the submaximal trial. For all subjects, maximal exercise sessions preceded the submaximal sessions. The submaximal session consisted of three short bouts of exercise at RPE levels 11, 13 and 15 on each exercise modality. Subject's assignment for modality and RPE intensity level were partially randomized but balanced. As a result, 12 permutations for each gender were required: six for the RPE order and two for modality. Prior to the first maximal test, height, weight, and age were recorded. Weight was recorded again on each testing day so that relative VO_2 values could be calculated accurately.

Maximal Trial

Before the first maximal trial for each subject, he or she was instructed on the test protocol and proper use of the treadmill (Precor, 954, Woodinville, WA) or elliptical trainer

(Precor, EFX 546, Woodinville, WA). This was followed by a 5-min warm-up at a self-selected pace on modality selected for that day of testing. After the warm-up, the subject was read the following standard set of instructions, which explained RPE scale use:

> During the exercise test we want you to pay close attention to how hard you feel the exercise work rate is. The feeling should reflect your total amount of exertion and fatigue, combining all sensations and feeling of physical stress, effort and fatigue. Do not concern yourself with any one factor such as leg pain, shortness of breath or exercise intensity, but try to concentrate on your total, inner feeling of exertion. Try not to underestimate or overestimate your feeling of exertion; be as accurate as you can (ACSM, 2000).

The subject was then fitted with a heart rate monitor (Polar, A3, Irvine, CA) and connected to the metabolic cart (Parvo Medics Inc, TrueMax 2400, Sandy, UT). During the maximal treadmill test, the subject self-selected a comfortable running speed at zero percent grade. Grade was then increased by 2% every 2 min until the subject could no longer continue the test because of fatigue. Each subject was verbally encouraged to reach exhaustion during test. In the elliptical trainer test the subjects self-selected a stride cadence. Like the treadmill test, the elliptical trainer test also consisted of 2 min stages starting at no resistance; load was increased by two machine levels for every 2 min thereafter until the subjects reached volitional exhaustion or could not maintain the proper cadence. Each subject was encouraged to maintain the initial self-selected cadence throughout the test. If cadence fell, the subject was verbally encouraged to speed up.

In both maximum tests, respiratory metabolic measurements were made every 15 s by the metabolic cart, while HR and RPE were measured 15 s before the end of each stage. Maximal oxygen uptake for both the treadmill and elliptical trainer was determined by taking the average of the last three values of the last stage. If the subject completed at least 1.5 min of the final stage, the last three values of that stage were averaged together. Data were recorded on treadmill and elliptical trainer maximal data sheets (Appendix D & E).

Submaximal Trial

The second session for either modality consisted of three submaximal efforts at least 48 h but no more than one week after the maximal trial. On the submaximal exercise day, the subjects were asked to reproduce RPE values of 11 (fairly light), 13 (somewhat hard), and 15 (hard) on each modality with each exercise effort separated by at least 5 min of seated rest. Each subject's RPE intensity order was pre-assigned. Prior to each submaximal trial, subjects were asked to remain in a seated position for 5 min or until their HR returned to within 10 beats of resting depending on which came first.

Each submaximal RPE intensity trial was 6 min in length with the first 2 min used to adjust the work rate to achieve the desired RPE. The RPE scale was always placed in full view of the subject, who was asked to assess intensity as based on RPE. Previous experience from maximal tests was used a reference. Depending on modality, the subject then adjusted exercise intensity to achieve the desired RPE by self adjusting resistance, cadence, velocity and grade. The displays for these variables were covered to prevent the subject from seeing the actual values. Because the cadence value on the elliptical trainer was covered, the subjects were reminded to focus on keeping this value consistent. The experimenter periodically checked the cadence and told the subject to speed up or slow down if the cadence deviated too much from the original self-selected value. In the final minutes of each trial, the subjects were presumed to have obtained a steady state reflective of that given RPE value. Steady state was determined to have occurred if the exercise HR did not change by more than five beats between the fourth and sixth minute. If the HR did change by more than five beats, the subjects were asked to continue exercise until steady state was obtained. Metabolic measures and HR were obtained at 30 s intervals throughout each trial as previously described in the maximum exercise test section.

Values for steady state VO_2, HR, and RPE values were obtained by averaging the final three values from the last minute of each RPE intensity level. Absolute ($kcal \cdot min^{-1}$) and relative ($kcal \cdot min^{-1} \cdot kg^{-1}$) EE was calculated from steady state VO_2 and RER values. Data were recorded on treadmill and elliptical trainer submaximal maximal data sheets (Appendix F & G).

Statistical Analysis

Statistical analyses were completed for the maximal and submaximal sessions using SPSS (SPSS Science, Chicago, IL) version 11.0 for Windows. Maximal exercise data were analyzed using three 2 x 2 ANOVA comparing mode and gender for the dependent variables VO_{2max}, HR_{max}, and RPE_{max}. Submaximal exercise data were analyzed using six 2 x 2 x 3 ANOVA comparing mode, gender and RPE intensity level for the dependent variables submaximal VO_2, percentage of machine specific VO_{2max}, submaximal HR, percentage of machine specific HR_{max}, absolute EE and relative EE. Significance level was set at $p < 0.05$ and for any significant interaction, a Tukey HSD post-hoc analysis was completed. Raw data are located in Appendix H.

Chapter 4

RESULTS

A primary purpose of this study was to compare EE on the treadmill and elliptical trainer at three intensities gauged by RPE values. Additional physiological indicators of submaximal exercise such as submaximal VO_2 and HR were also compared at each RPE value. Physiological indicators of maximal exercise performance (VO_{2max}, HR_{max}, and RPE_{max}) were also measured and compared between the treadmill and elliptical trainer. A modality preference questionnaire was administered to determine if a modality bias existed for the subjects. Following data collection (raw data are located in Appendix H), the results were analyzed and are here presented in the following subsections: 1) Characteristics of subjects; 2) Maximum exercise testing: treadmill and elliptical trainer; 3) Submaximal exercise: treadmill and elliptical trainer; 4) Modality preference questionnaire; and 5) Summary.

Characteristics of Subjects

The subject's age, height, and weight were recorded on the first day of testing and are reported in Table 1. As expected, the males on average were taller (16.7 cm) and heavier (14.6 kg) than the females. The mean age of males ($M = 21.8$, $SE = 0.7$) was relatively close to females ($M = 20.6$, $SE = 0.5$), as subjects were selected from a cohort of college students.

Table 1

Height, weight and age of subjects

	Male (n = 12)		Female (n = 12)	
	M	*SE*	*M*	*SE*
Height (cm)	159.5*	1.2	142.8*	0.7
Weight (kg)	70.0*	5.5	55.3*	4.6
Age (y)	21.8	0.7	20.6	0.5

Note:

M = mean and *SE* = standard error.

* denotes a significant difference between males and females ($p < 0.05$).

Maximum Exercise Testing: Treadmill and Elliptical Trainer

Analysis (2 x 2 ANOVA) of VO_{2max} ($ml \cdot min^{-1} \cdot kg^{-1}$), HR_{max} (bpm), and RPE_{max} from maximum exercise testing allowed for comparisons by modality and gender. There was no significant interaction between mode and gender for VO_{2max} (Table 2). There was, however a significant main effect for mode of exercise on VO_{2max} (F (1, 22) = 32.1; p = 0.000), with the treadmill (50.4 ± 1.13 $ml \cdot min^{-1} \cdot kg^{-1}$) producing higher VO_{2max} values than the elliptical trainer (45.6 ± 0.72 $ml \cdot min^{-1} \cdot kg^{-1}$) (Table 3). There was also a significant main effect for gender on VO_{2max} (F (1, 22) = 21.1; p = 0.000) with males producing higher values (51.9 ± 1.21 $ml \cdot min^{-1} \cdot kg^{-1}$) than females (44.1 ± 1.21 $ml \cdot min^{-1} \cdot kg^{-1}$).

There was no significant interaction between mode and gender for HR_{max} (Table 4). There was, however, a significant main effect for mode of exercise (F (1, 22) = 15.5; p = 0.001), with the treadmill (192 ± 2.0 bpm) producing higher HR_{max} values than the elliptical trainer (187 ± 1.8 bpm) (Table 5). Unlike VO_{2max}, there was no significant gender main effect for HR_{max}.

There was no interaction between mode and gender for RPE_{max} (Table 6). There was, however, a significant main effect for gender (F (1, 22) = 5.2; p = 0.033), with males reporting a higher RPE_{max} (17.8 ± 0.21) than the females (17.1 ± 0.17) (Table 7). Unlike VO_{2max} and HR_{max}, there was no main effect for mode on maximum RPE.

Submaximal Exercise: Treadmill and Elliptical Trainer

Submaximal exercise data were analyzed using six (2 x 2 x 3) repeated measures ANOVA comparing mode, gender, and RPE level for the dependent variables VO_2

Table 2

VO_{2max}: ANOVA summary table (mode x gender)

Source	SS	df	MS	*F*	*p*
Mode	267.0	1	267.0	32.1	0.000[a]
Mode x Gender	16.8	1	16.8	2.0	0.169
Residual	182.7	22	8.3		
Between Subjects					
Gender	737.9	1	737.9	21.1	0.000[b]
Residual	771.1	22	35.0		

Note:

[a] denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

[b] denotes a significant difference between males and females ($p < 0.05$).

Table 3

Relative VO_{2max} ($ml \cdot min^{-1} \cdot kg^{-1}$) on treadmill and elliptical trainer

	Male (n = 12)		Female (n = 12)		Total (n = 24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
Treadmill	54.9	1.84	45.8	1.33	50.4[a]	1.13
Elliptical	49.0	1.20	42.3	0.80	45.6[a]	0.72
Grand Mean	51.9[b]	1.21	44.1[b]	1.21	46.7	1.02

Note:

M = mean and *SE* = standard error.

[a] denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

[b] denotes a significant difference between genders ($p < 0.05$)

Table 4

HR_{max}: ANOVA summary table (mode x gender)

Source	SS	df	MS	*F*	*p*
Mode	320.3	1	320.3	15.5	0.001*
Mode x Gender	18.8	1	18.8	0.9	0.352
Residual	455.9	22	20.7		
Between Subjects					
Gender	24.1	1	24.1	0.2	0.699
Residual	3454.9	22	157.0		

Note:

* denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

Table 5

HR_{max} on treadmill and elliptical trainer

	Male (n = 12)		Female (n = 12)		Total (n = 24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
Treadmill	193	2.6	191	3.0	192*	2.0
Elliptical	187	2.6	187	2.7	187*	1.8
Grand Mean	190	2.6	189	2.6	190	1.9

Note:

M = mean and *SE* = standard error.

HR_{max} reported in bpm, * denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

Table 6

RPE_{max}: ANOVA summary table (mode x gender)

Source	SS	df	MS	*F*	*p*
Mode	1.3	1	1.3	1.6	0.222
Mode x Gender	2.1	1	2.1	2.5	0.131
Residual	18.6	22	0.8		
Between Subjects					
Gender	5.3	1	5.3	5.2	0.033*
Residual	22.6	22	1.0		

Note:

* denotes a significant difference between males and females ($p < 0.05$).

Table 7

RPE_{max} on treadmill and elliptical trainer

	Male (n = 12)		Female (n = 12)		Total (n = 24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
Treadmill	17.8	0.35	17.5	0.26	17.63	0.22
Elliptical	17.8	0.27	16.8	0.22	17.29	0.17
Grand Mean	17.8*	0.21	17.1*	0.17	17.46	0.20

Note:

M = mean and *SE* = standard error.

RPE reported on 15 point scale (Borg, 1982). * denotes a significant difference between males and females ($p < 0.05$).

(ml·min^{-1}·kg^{-1}); percentage of machine specific VO_{2max}, HR (bpm), percentage of machine specific HR_{max} and EE (kcal·min^{-1} and kcal·min^{-1}·kg^{-1}).

There were no interactions between mode, gender, and RPE level for submaximal VO_2 (Table 8). There was, however, a significant main effect for mode (F (1, 22) = 29.0; p = 0.000), with the treadmill (36.0 ± 1.12 ml·min^{-1}·kg^{-1}) producing higher values than the elliptical trainer (31.1 ± 1.09 ml·min^{-1}·kg^{-1}). As expected there was also a significant main effect for intensity (RPE) on submaximal VO_2 (F (2, 44) = 204.6; p = 0.000). The hard (RPE 15) intensity level (39.1 ± 1.25 ml·min^{-1}·kg^{-1}) elicited a significantly higher submaximal VO_2 than the moderate (RPE 13) intensity (33.5 ± 1.04 ml·min^{-1}·kg^{-1}), which elicited a significantly higher VO_2 than the light (RPE 11) intensity (27.7 ± 1.00 ml·min^{-1}·kg^{-1}). Mean data for submaximal VO_2 are located in Tables 9 and 10. There was a significant main effect for gender on submaximal VO_2 (F (1, 22) = 7.1; p = 0.014), with the male subjects (35.7 ± 1.24 ml·min^{-1}·kg^{-1}) producing higher values than female subjects (31.4 ± 1.24 ml·min^{-1}·kg^{-1}). There was also a significant main effect for mode on submaximal VO_2 (F (1, 22) = 29.0; p = 0.000), with the treadmill (36.0 ± 1.12 ml·min^{-1}·kg^{-1}) producing higher values than the elliptical trainer (31.1 ± 1.09 ml·min^{-1}·kg^{-1}).

For each subject, submaximal VO_2 was converted to a percentage of the machine specific VO_{2max}. There was a significant interaction (Table 11) between mode and RPE (F (2, 44) = 3.6; p = 0.035). A Tukey HSD post-hoc analysis revealed that the subjects were working at a higher relative submaximal VO_2 on the treadmill (61.24 ± 1.98 $\%VO_{2max}$) compared to the elliptical trainer (54.72 ± 2.28 $\%VO_{2max}$) at the light (RPE 11) intensity (Table 12). Unlike submaximal VO_2, there was no significant main effect for mode. As

Table 8

Submaximal VO_2: ANOVA summary table (mode x gender x RPE)

Source	SS	df	MS	F	p
Mode	872.5	1	872.5	29.0	0.000[a]
Mode x Gender	68.9	1	68.9	2.3	0.145
Error 1	662.7	22	30.1		
RPE	3234.7	2	1617.3	204.6	0.000[b]
RPE x Gender	23.0	2	11.5	1.5	0.245
Error 2	347.9	44	7.9		
Mode x RPE	18.6	2	9.3	1.5	0.229
Mode x RPE x Gender	2.4	2	1.2	0.2	0.821
Residual	268.1	44	6.1		
Between Subjects					
Gender	678.9	1	678.9	7.1	0.014[c]
Residual	2103.3	22	95.6		

Note:

[a] denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

[b] denotes a significant difference between RPE ($p < 0.05$).

[c] denotes a significant difference between males and females ($p < 0.05$).

Table 9

Submaximal VO_2 (RPE x gender)

	Male (n = 12)		Female (n = 12)		Total (n = 24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
RPE 11	29.3	1.10	26.1	1.10	27.7[a]	1.00
RPE 13	36.0	1.22	31.4	1.22	33.5[a]	1.04
RPE 15	41.9	1.39	36.7	1.37	39.1[a]	1.25
Grand Mean	35.7[b]	1.24	31.4[b]	1.23	33.4	1.10

Note:

M = mean and *SE* = standard error.

submaximal VO_2 reported in $ml \cdot min^{-1} \cdot kg^{-1}$.

submaximal VO_2 values represent average of treadmill and elliptical trainer.

[a] denotes a significant difference between RPE ($p < 0.05$).

[b] denotes a significant difference between males and females ($p < 0.05$).

Table 10

Submaximal VO_2 (RPE x mode)

	Treadmill (n = 24)		Elliptical (n = 24)	
	M	*SE*	*M*	*SE*
RPE 11	30.6	1.01	24.8	1.00
RPE 13	36.2	1.15	31.2	0.98
RPE 15	41.3	1.19	37.3	1.28
Grand Mean	36.0*	1.12	31.1*	1.09

Note:

M = mean and *SE* = standard error.

submaximal VO_2 reported in $ml \cdot min^{-1} \cdot kg^{-1}$.

submaximal VO_2 values represent average of males and females.

* denotes a significant difference between treadmill and

elliptical trainer ($p < 0.05$).

Table 11

Percentage of machine specific VO_{2max}: ANOVA summary table (mode x gender x RPE)

Source	SS	df	MS	*F*	*p*
Mode	496.7	1	496.7	3.0	0.096
Mode x Gender	36.1	1	36.1	0.2	0.644
Error 1	3609.2	22	164.1		
RPE	14048.9	2	7024.4	235.0	0.000[a]
RPE x Gender	6.4	2	3.2	0.1	0.898
Error 2	1315.4	44	29.9		
Mode x RPE	205.6	2	102.8	3.6	0.035[b]
Mode x RPE x Gender	16.7	2	8.3	0.3	0.746
Residual	1247.0	44	28.3		
Between Subjects					
Gender	192.4	1	192.4	0.4	0.511
Residual	9495.4	22	431.6		

Note:

[a] denotes a significant difference between RPE ($p < 0.05$).

[b] denotes a significant interaction between gender and RPE ($p < 0.05$).

Table 12

Percentage of machine specific VO_{2max} (RPE x mode)

	Treadmill (n=24)		Elliptical (n=24)	
	M	*SE*	*M*	*SE*
RPE 11	61.24*	1.98	54.72*	2.28
RPE 13	72.53	2.27	68.58	2.23
RPE 15	82.50	2.05	81.83	2.50
Grand Mean	72.09	2.10	68.37	2.34

Note:

M = mean and *SE* = standard error.

percentages of VO_{2max} represent average of males and females.

* denotes a significant difference between treadmill and

elliptical trainer (RPE 11) ($p < 0.05$).

expected, there was a significant main effect for intensity (RPE) on percentage of machine specific VO_{2max} (F (2, 44) = 235.0; p = 0.000). As shown in Table 13 the hard (RPE 15) intensity level (82.17 ± 1.83 %VO_{2max}) elicited a significantly higher percentage of VO_{2max} than the moderate (RPE 13) intensity (70.55 ± 1.90 %VO_{2max}), while the moderate intensity level was significantly higher than the light (RPE 11) intensity (57.98 ± 1.81 %VO_{2max}). Unlike submaximal VO_2, there was no main effect for gender, with male and female subjects working at similar percentages of maximum.

There were no interactions between mode, gender, or RPE for submaximal HR (Table 14). There was however, a significant main effect for mode (F (1, 22) = 17.6; p = 0.000), with the treadmill producing higher submaximal HR (164.7 ± 3.0 bpm) than the elliptical trainer (153.7 ± 3.0 bpm). There was also an expected significant main effect for intensity (RPE) (F (2, 44) = 170.6; p = 0.000). As shown in Tables 15 and 16, submaximal HR for the hard (RPE 15) intensity (171.9 ± 3.0 bpm) was significantly higher than the moderate (RPE 13) intensity (160.2 ± 2.8 bpm), which in turn was significantly higher than the light (RPE 11) intensity (145.4 ± 3.2 bpm).

Similar to percentage of machine specific VO_{2max}, submaximal HR was also converted to a percentage of machine specific HR_{max}. There were no significant interactions between mode, gender, or RPE (Table 17); however, there was a significant main effect for mode (F (1, 22) = 7.1; p = 0.014). The treadmill produced higher machine specific percentages of HR_{max} (85.82 ± 1.40 %HR_{max}) than the elliptical trainer (82.15 ± 1.30 %HR_{max}) across all RPE intensities and both genders. There was also the expected significant main effect for intensity (RPE) on percentage of machine specific HR_{max} (F (2, 44) = 182.5; p = 0.000). As shown in Tables 18 and 19, percentage of HR_{max} for the hard (RPE 15) intensity

Table 13

Percentage of machine specific VO_{2max} (RPE x gender)

	Male (n=12)		Female (n=12)		Total (n=24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
RPE 11	56.68	2.56	59.28	2.56	57.98*	1.81
RPE 13	69.70	2.68	71.41	2.68	70.55*	1.90
RPE 15	80.86	2.59	83.48	2.59	82.17*	1.83
Grand Mean	69.08	2.45	71.39	2.45	70.23	1.85

Note:

M = mean and *SE* = standard error.

percentages of VO_{2max} represent average of treadmill and elliptical trainer.

* denotes a significant difference between RPE ($p < 0.05$).

Table 14

Submaximal HR: ANOVA summary table (mode x gender x RPE)

Source	SS	df	MS	*F*	*p*
Mode	4392.7	1	4392.7	17.6	0.000[a]
Mode x Gender	154.9	1	154.9	0.6	0.440
Error 1	5499.4	22	250.0		
RPE	16894.7	2	8447.4	170.6	0.000[b]
RPE x Gender	54.0	2	27.0	0.5	0.583
Error 2	2178.8	44	49.5		
Mode x RPE	165.4	2	82.7	2.1	0.138
Mode x RPE x Gender	38.8	2	19.4	0.5	0.618
Residual	1754.4	44	39.9		
Between Subjects					
Gender	332.0	1	332.0	0.4	0.544
Residual	19201.7	22	872.8		

Note:

[a] denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

[b] denotes a significant difference between RPE ($p < 0.05$).

Table 15

Submaximal HR (gender x RPE)

	Male (n = 12)		Female (n = 12)		Total (n = 24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
RPE 11	143.2	3.7	147.7	3.7	145.4*	3.2
RPE 13	159.4	3.5	161.0	3.5	160.2*	2.8
RPE 15	170.4	3.7	173.4	3.8	171.9*	3.0
Grand Mean	157.7	3.6	160.7	3.7	159.2	3.0

Note:

M = mean and *SE* = standard error.

submaximal HR reported in bpm.

submaximal HR values represent average of treadmill and elliptical trainer.

* denotes a significant difference among RPE ($p < 0.05$).

Table 16

Submaximal HR (mode x RPE)

	Treadmill (n = 24)		Elliptical (n = 24)	
	M	*SE*	*M*	*SE*
RPE 11	152.2	3.1	138.7	3.2
RPE 13	165.9	2.9	154.5	2.6
RPE 15	176.0	2.9	167.8	3.1
Grand Mean	164.7*	3.0	153.7*	3.0

Note:

M = mean and *SE* = standard error.

submaximal HR reported in bpm.

submaximal HR values represent average of males and females.

* denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

Table 17

Percentage of machine specific HR_{max}: ANOVA summary table (mode x gender x RPE)

Source	SS	df	MS	*F*	*p*
Mode	484.9	1	484.9	7.1	0.014[a]
Mode x Gender	12.2	1	12.2	0.2	0.676
Error 1	1502.1	22	68.3		
RPE	4717.4	2	2358.7	182.5	0.000[b]
RPE x Gender	12.5	2	6.3	0.5	0.620
Error 2	568.6	44	12.9		
Mode x RPE	53.1	2	26.6	2.4	0.100
Mode x RPE x Gender	8.5	2	4.2	0.4	0.681
Residual	482.3	44	11.0		
Between Subjects					
Gender	163.8	1	163.8	1.1	0.308
Residual	3308.2	22	150.4		

Note:

[a] denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

[b] denotes a significant difference between RPE ($p < 0.05$).

Table 18

Percentage of machine specific HR_{max} (RPE x gender)

	Male (n=12)		Female (n=12)		Total (n=24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
RPE 11	75.30	1.69	78.12	1.69	76.71*	1.19
RPE 13	83.84	1.48	85.22	1.48	84.53*	1.05
RPE 15	89.60	1.51	91.80	1.51	90.70*	1.07
Grand Mean	85.82	1.31	82.15	1.14	83.98	1.10

Note:

M = mean and *SE* = standard error.

percentages of HR_{max} represent average of treadmill and elliptical trainer.

* denotes a significant difference among RPE ($p < 0.05$).

Table 19

Percentage of machine specific HR_{max} (RPE x mode)

	Treadmill (n=24)		Elliptical (n=24)	
	M	*SE*	*M*	*SE*
RPE 11	79.23	1.50	74.20	1.52
RPE 13	86.47	1.41	82.59	1.12
RPE 15	91.75	1.30	89.66	1.26
Grand Mean	85.82*	1.40	82.15*	1.30

Note:

M = mean and *SE* = standard error.

percentages of HR_{max} represent average of males and females.

* denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

(90.70 ± 1.07 $\%HR_{max}$) was significantly higher than the moderate (RPE 13) intensity (84.53 ± 1.05 $\%HR_{max}$), which in turn was significantly higher than the light (RPE 11) intensity (76.71 ± 1.19 $\%HR_{max}$).

There was a significant interaction (Table 20) between gender and RPE for absolute caloric expenditure (F (1, 22) = 6.2; p = 0.021). A Tukey HSD post-hoc analysis showed that males had a greater absolute caloric expenditure than females on all comparisons except males RPE 11 versus females RPE 15. This would be expected due to the fact that the male subjects weigh more and therefore burn more total calories and display a greater absolute rate of change between different intensity levels. As shown in Tables 21 and 22, there was also a significant main effect for mode (F (1, 22) = 27.6; p = 0.000), with the treadmill (13.13 ± 0.70 $kcal \cdot min^{-1}$) producing a greater caloric expenditures than the elliptical trainer (11.19 ± 0.37 $kcal \cdot min^{-1}$) across all intensities and for both genders (Table 21). EE also increased with increases in exercise intensity (F (2, 44) = 202.7; p = 0.000). It was also found that a significant gender difference existed in absolute caloric expenditure (F (1, 22) = 44.4; p = 0.000) with the males (14.38 ± 0.50 $kcal \cdot min^{-1}$) burning more calories than the females (9.94 ± 0.51 $kcal \cdot min^{-1}$) across all three intensities (Table 22).

Since males weigh more than females, differences in absolute EE were expected. To better understand how the machines altered EE, the relative EE ($kcal \cdot min^{-1} \cdot kg^{-1}$) was also examined. There were no interactions between mode, RPE, and gender (Table 23). There was however, a significant main effect for mode (F (1, 22) = 27.4; p = 0.000), with the treadmill expending more energy per kg of bodyweight (0.180 ± 0.006 $kcal \cdot min^{-1} \cdot kg^{-1}$) than the elliptical trainer (0.155 ± 0.006 $kcal \cdot min^{-1} \cdot kg^{-1}$) across all intensities and both genders (Table 24). There was also a main effect for intensity (F (2, 44) = 200.1; p = 0.000). As with

Table 20

Absolute caloric expenditure: ANOVA summary table (mode x gender x RPE)

Source	SS	df	MS	*F*	*p*
Mode	134.9	1	134.9	27.6	0.000[a]
Mode x Gender	19.3	1	19.3	4.0	0.059
Error 1	107.4	22	4.9		
RPE	462.5	2	231.2	202.7	0.000[b]
RPE x Gender	19.3	2	9.6	8.4	0.001[c]
Error 2	50.2	44	1.1		
Mode x RPE	1.8	2	0.9	0.9	0.398
Mode x RPE x Gender	0.6	2	0.3	0.3	0.739
Residual	41.6	44	0.9		
Between Subjects					
Gender	707.9	1	707.9	44.4	0.000[d]
Residual	351.0	22	16.0		

Note:

[a] denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

[b] denotes a significant difference between RPE ($p < 0.05$).

[c] denotes a significant interaction between genders and RPE ($p < 0.05$).

[d] denotes a significant difference between males and females ($p < 0.05$).

Table 21

Absolute caloric expenditure (mode x RPE)

	Treadmill (n = 24)		Elliptical (n = 24)	
	M	*SE*	*M*	*SE*
RPE 11	11.04	0.60	8.83	0.33
RPE 13	13.19	0.70	11.26	0.35
RPE 15	15.15	0.80	13.49	0.41
Grand Mean	13.13*	0.70	11.19*	0.37

Note:

M = mean and *SE* = standard error.

absolute caloric expenditure reported in $kcal \cdot min^{-1}$.

caloric expenditure represents average of males and females.

* denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

Table 22

Absolute caloric expenditure (gender x RPE)

	[a]Male (n = 12)		[a]Female (n = 12)		Total (n = 24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
RPE 11	11.67	0.43	8.19	0.43	9.93[b]	0.52
RPE 13	14.52	0.52	9.93	0.55	12.15[b]	0.61
RPE 15	16.94	0.55	11.70	0.54	14.20[b]	0.70
Grand Mean	14.38[c]	0.50	9.94[c]	0.51	12.11	0.61

Note:

M = mean and *SE* = standard error.

absolute caloric expenditure reported in kcal·min^{-1}.

caloric expenditure represents average of treadmill and elliptical trainer.

[a] denotes a significant interaction between RPE and gender ($p < 0.05$) with male light (RPE 11) intensity the same as the female hard (RPE 15) intensity.

[b] denotes a significant difference between RPE ($p < 0.05$).

[c] denotes a significant difference between males and females ($p < 0.05$).

Table 23

Relative caloric expenditure: ANOVA summary table (mode x gender x RPE)

Source	SS	df	MS	*F*	*p*
Mode	0.0220	1	0.0220	27.4	0.000[a]
Mode x Gender	0.0017	1	0.0017	2.1	0.159
Error 1	0.0176	22	0.0008		
RPE	0.0877	2	0.0439	200.1	0.000[b]
RPE x Gender	0.0006	2	0.0003	1.4	0.263
Error 2	0.0096	44	0.0002		
Mode x RPE	0.0004	2	0.0002	1.3	0.281
Mode x RPE x Gender	0.0001	2	0.0000	0.3	0.748
Residual	0.0072	44	0.0002		
Between Subjects					
Gender	0.0169	1	0.0169	6.9	0.016[c]
Residual	0.0540	22	0.0025		

Note:

[a] denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

[b] denotes a significant difference between RPE ($p < 0.05$).

[c] denotes a significant difference between genders ($p < 0.05$).

Table 24

Relative Caloric Expenditure (mode x RPE)

	Treadmill (n = 24)		Elliptical (n = 24)	
	M	*SE*	*M*	*SE*
RPE 11	0.151	0.005	0.123	0.005
RPE 13	0.181	0.005	0.156	0.005
RPE 15	0.208	0.005	0.187	0.007
Grand Mean	0.180*	0.005	0.155*	0.005

Note:

M = mean and *SE* = standard error.

relative caloric expenditure is represented in $kcal \cdot min^{-1} \cdot kg^{-1}$.

caloric expenditure represents average of males and females.

* denotes a significant difference between treadmill and elliptical trainer ($p < 0.05$).

absolute caloric expenditure, greater intensities (RPE level) caused higher caloric expenditure (Table 25). Finally, there was also a significant unexpected main effect for gender (F (1, 22) = 6.9; $p = 0.016$), with males (0.178 ± 0.006 kcal·min^{-1}·kg^{-1}) expending more calories per kg of body weight than females (0.157 ± 0.006 kcal·min^{-1}·kg^{-1}) across all intensities and both modalities (Table 25).

Modality Preference Questionnaire

The questionnaire was given prior to testing and the results can be seen in Tables 26 and 27. The first question asked the subjects to rate six modes of cardiovascular exercise on a scale from one (least favorable) to five (most favorable). There was also a sixth option labeled "N/A" if the subject had never used that mode of exercise. The results of question one revealed that overground running received the highest ratings (4.13 ± 0.25) for both genders compared to the other modalities. The treadmill and elliptical trainer followed overground running with very little difference in preference between these modes of exercise. The ski machine received the lowest ratings for both genders (1.80 ± 0.26). The second question only concerned the treadmill and the elliptical trainer. This question asked the subject to rate their desire to use one machine over the other. A response of one reflected a strong desire for the treadmill and a response of five reflected a strong desire for the elliptical trainer. A response of three reflected an equal preference for both machines. Subjects preferred the treadmill (responses of 1 and 2) in 16 of 24 cases, whereas 7 subjects preferred the elliptical trainer (responses of 4 and 5). Only one subject selected an equal preference for either mode. In other words, about twice as many subjects in this study preferred the treadmill.

Table 25

Relative Caloric Expenditure (gender x RPE)

	Male (n = 12)		Female (n = 12)		Total (n = 24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
RPE 11	0.145	0.006	0.129	0.006	0.137[a]	0.004
RPE 13	0.180	0.006	0.156	0.006	0.168[a]	0.004
RPE 15	0.210	0.007	0.185	0.007	0.197[a]	0.005
Grand Mean	0.178[b]	0.006	0.157[b]	0.006	0.168	0.004

Note:

M = mean and *SE* = standard error.

relative caloric expenditure is represented in $kcal \cdot min^{-1} \cdot kg^{-1}$.

caloric expenditure represents average of treadmill and elliptical trainer.

[a] denotes a significant difference between RPE ($p < 0.05$).

[b] denotes a significant difference between genders ($p < 0.05$).

Table 26

Exercise preference question results

	Male (n = 12)		Female (n = 12)		Total (n = 24)	
	M	*SE*	*M*	*SE*	*M*	*SE*
Running Overground	4.00	0.35	4.25	0.37	4.13	0.25
Treadmill	3.42	0.34	3.33	0.26	3.38	0.21
Elliptical Trainer	3.33	0.38	3.33	0.36	3.33	0.25
Stationary Bike	3.50	0.26	3.00	0.44	3.25	0.26
Stepper	3.00[a]	0.36	2.83	0.42	2.91	0.27
Ski Machine	2.13[b]	0.40	1.43[c]	0.30	1.80	0.26

Note:

M = mean and *SE* = standard error.

a score of 5 reflects most preferred while 1 reflects least preferred.

[a] one male subject reported not using the stepper.

[b] four male subjects reported not using the ski machine.

[c] five female subjects reported not using the ski machine.

Table 27

Treadmill vs. elliptical trainer question results

Rating	Male (n = 12)	Female (n = 12)	Total (n = 24)
1 (Treadmill)	3	2	5
2	6	5	11
3 (Equal)	0	1	1
4	1	3	4
5 (ET)	2	1	3

Note:

data are a frequency representation of the number subjects that selected the appropriate answer.

Summary

Maximal and submaximal data were recorded and analyzed. For maximal exercise, the treadmill produced higher VO_{2max} and HR_{max} than the elliptical trainer. In addition, males achieved a higher VO_{2max} than females across both modes of exercise. For submaximal exercise, the treadmill produced significantly higher submaximal VO_2, submaximal HR, and EE than the elliptical trainer across all intensities for both genders. Males tended to have a higher submaximal VO_2 than the females, but similar submaximal HRs. For percentage of machine specific VO_{2max}, the treadmill produced a higher percentage than the elliptical trainer only for the light (RPE 11) intensity. For percentage of machine specific HR_{max}, however, the treadmill produced a greater percentage than the elliptical trainer for across all intensities for both genders. There were no gender differences for percentage of machine specific VO_{2max} and HR_{max}. For absolute and relative EE, the males burned more calories than the females across all three intensities. The modality preference questionnaire showed that when compared to other common exercise modalities the treadmill and elliptical trainer ranked about equal. However, when compared just to each other, majority of the subjects preferred the treadmill.

Chapter 5

DISCUSSION

The purpose of this study was to compare the treadmill and the elliptical trainer in terms of physiological responses, particularly EE, at three intensities gauged using RPE values. With a variety of equipment options for cardiovascular exercise, research is needed to help consumers compare and choose a device that best suits their needs. Exercise on machines such as a treadmill, cycle ergometer, stepper and rowing ergometer produce an adequate exercise stimulus; however, choosing a machine that produces the greatest caloric expenditure with the least amount of strain or feeling of exertion may be the most desirable. By this standard, previous research has revealed that the treadmill is a superior exercise machine compared to the other modalities (Hetzler et al., 1991; Kravitz et al., 1997; Moyna et al., 2001; Zeni et al., 1996). The elliptical trainer, despite increasing popularity as an alternative to the treadmill, has received little research attention. This chapter is divided into the following categories: 1) Maximal exercise testing; 2) Submaximal VO_2, HR, and EE; 3) percentage of machine specific VO_{2max} and HR_{max}; 4) Gender differences in submaximal exercise; 5) Practical applications, and 6) Summary.

Maximal Exercise Testing

Maximal exercise testing was conducted on both modalities to examine differences in maximal exercise response (VO_{2max}, HR_{max}, and RPE_{max}). Maximum testing also served to help familiarize the subjects with the RPE scale. It was found that the subjects' VO_{2max} values were above average for published age and gender specific values (ACSM, 2000), which was expected given that the subjects had been training prior to participating in the study. It was also found that higher VO_{2max} and HR_{max} values were elicited on the treadmill rather than the elliptical trainer. These data contrast with data from Mercer et al. (2001), who found that similar VO_{2max} and HR_{max} values were elicited on the treadmill and elliptical trainer.

A possible explanation for the inconsistency between the studies is the testing protocols used to elicit VO_{2max} and HR_{max}. The treadmill GXT used by Mercer et al. (2001), for example, consisted of one-minute stages with changes in speed and a constant incline (8% grade), while in the present study, a constant speed with 2% grade increase every 2 min was employed. The incline setting used by Mercer et al. coupled with unlimited increases in speed may have reduced their subjects' ability to achieve a true treadmill VO_{2max} and HR_{max}, as running speed is often limited by muscle function rather than cardiovascular capacity. For the elliptical trainer GXT, Mercer et al. increased both cadence and resistance, whereas in the present study only resistance was increased, which may have limited the ability of this study's subjects to achieve a true elliptical trainer VO_{2max} and HR_{max}. This supposition is supported by the fact that many subjects in the present study complained of leg fatigue after the elliptical trainer maximum test, a consequence of the high resistance needed to elicit VO_{2max}. This supposition is also supported by data from Monya et al. (2001), who found that the cycle ergometer elicited lower VO_{2max} values than the treadmill, cross country ski stepper, aerobic rider, and rowing ergometer machine. The authors suggested that localized leg fatigue may have limited VO_{2max} on the cycle ergometer, where VO_{2max} is obtained by only increasing resistance, as with the protocol used to elicit VO_{2max} on the elliptical trainer in the present study. Further research is needed to explore the possibility of leg fatigue limiting maximum results on the elliptical trainer.

Another possible explanation for differences in VO_{2max} and HR_{max} data between Mercer et al. (2001) and the present study may have been the model of the elliptical trainer that was used in each. Like in this study, Mercer et al. (2001) used a Precor elliptical trainer, but they did not report what model they used. If the model had movable handlebars, it would have required their subjects to use their upper body during the GXT. Upper body movement during the GXT may have allowed subjects in Mercer et al. to achieve a higher elliptical trainer VO_{2max} than subjects in this study, who tested on an elliptical trainer that had fixed handlebars. Since Mercer et al. is the only other study examining a maximal GXT on the elliptical trainer, more research is needed determine if the elliptical trainer can be used to elicit true VO_{2max} and HR_{max} values.

As expected, males in this study obtained a higher VO_{2max} than females across both modalities. The difference in VO_{2max} across gender is ascribed to a variety factors. The primary explanations include the fact that males are typically larger, which means they have a bigger heart and pulmonary capacity (Drinkwater, 1973; Kravitz et al., 1997). Males also have a higher hemoglobin concentration, a consequence of higher androgen levels, which means that each liter of blood in a male can carry more oxygen (Drinkwater, 1973; Kravitz et al., 1997). Unexpectedly, however, HR_{max} was similar for both genders across both modalities. Given that males typically have a larger heart, and therefore, stroke volume than females, it was expected that HR_{max} would be higher in females. However, consistent with the present study, other authors report similar HR_{max} between males and females (Kravitz et al., 1997; Robertson et al., 2000; Whaley, Kaminsky, Dwyer, Getchell, & Nortan, 1992). Males also achieved a significantly higher RPE_{max} than females across both modalities. It is unknown why a gender difference in RPE_{max} occurred. This finding is inconsistent with

Robertson et al. (2000), who found no cross-modal (treadmill and cycle ergometer) difference in RPE_{max} between genders. Robertson et al. did not, however, include an elliptical trainer in their study, so a direct comparison is difficult.

Even though the elliptical trainer elicited lower VO_{2max} and HR_{max} values than the treadmill, it may still be an adequate GXT modality. If a person is unable to perform a treadmill GXT because of orthopedic or other considerations, the cycle ergometer is normally substituted. The use of an elliptical trainer may be a better substitute, as the exercise motion more closely resembles the walking stride that most people are more comfortable with relative to the less familiar cycling motion. If an elliptical trainer is used for a GXT, a high cadence may need to be maintained to prevent excessive increases in resistance, which should help to minimize localize leg fatigues. It would be instructive to compare cycle ergometer maximal exercise values to those obtained using an elliptical trainer.

Submaximal VO_2, HR, and EE

During submaximal exercise testing, six physiological variables were compared between the treadmill and elliptical trainer at three intensities gauged by RPE level (11, 13 & 15). These variables were: submaximal VO_2, percentage of machine based VO_{2max}, submaximal HR, percentage of machine based HR_{max}, and absolute and relative EE. These physiological variables are an indication of exercise metabolism and are strongly correlated with each other. EE, which is directly proportional to VO_2, is the variable of interest to most people, because of how it affects weight management. It was found that subjects had a higher submaximal VO_2, HR, and absolute and relative EE values across the three RPE-gauged intensities on the treadmill compared to the elliptical trainer. There was no gender effect.

The EE data from this study are inconsistent with the literature in which it is reported that the elliptical trainer elicits similar or greater EE than the treadmill (Kim 1999; Porcari et al. 2000; and Spranger et al. 1998). Possible reasons for this inconsistency include the means by which exercise intensity was gauged, the weight of the subjects studied, and type of elliptical trainer that was used. The present study, for example, used the RPE scale to gauge exercise intensity, whereas Porcari et al. asked subjects to exercise at their personal estimate of a moderate intensity. RPE is well accepted and widely used for exercise prescription, and provides a structured gauge of intensity, whereas asking subjects to exercise at a "moderate intensity" may be too subjective. In Kim, for example, obese individuals served as subjects in contrast to the normal weight individuals in the present study. The low impact nature of the elliptical trainer may have allowed the obese subjects in Kim to obtain a similar or greater VO_2, and therefore, EE at each workload on the elliptical trainer than the treadmill, which is a higher impact aerobic exercise. The high impact nature of the treadmill may not have limited the normal weight subjects in the present study; thus, they could do more work at each RPE on the treadmill than the elliptical trainer, which lead to a greater VO_2, and therefore, EE. Last, Kim used an elliptical trainer that had a movable arm component, whereas the present study did not. The effect of the movable arm component on perception of intensity is unknown. The results from the present study are, however, in general agreement with data from other studies that show that the treadmill elicits a greater EE than other exercise modalities at various intensities of exercise (Kravitz et al., 1997; Moyna et al., 2001; Zeni et al., 1996).

One possible explanation for why the treadmill elicited a greater EE than the elliptical trainer in this study at the three exercise intensities is that the subjects may have experienced greater localized leg fatigue on the elliptical trainer. If so, they may have then perceived the elliptical trainer to be harder at a lower absolute intensity relative to the treadmill. This supposition is indirectly supported by the submaximal VO_2 data, which show that the subjects were consuming less oxygen, and therefore, less energy on the elliptical trainer than the treadmill at the three exercise intensities. In hindsight, it would have been beneficial to measure work output in this study so that this question could be answered more completely. Perhaps the elliptical trainer is more similar to the cycle ergometer than the treadmill, as the elliptical trainer and ergometer require a person to push a set resistance in a circular motion. The cycle ergometer, moreover, has been shown to elicit a higher perception of intensity because of localized leg fatigue than the treadmill at various exercise intensities (Zeni et al., 1996). In this study, perception of effort was well correlated to the blood lactate concentration. Future researchers may wish to measure the differences in work output, blood lactate concentration, and peripheral and central perceptions of effort to determine if the elliptical trainer produces greater localized leg fatigue, and therefore, lower EE than the treadmill at various intensities of exercise.

Another factor that may have led to a difference in EE between modalities is personal preference and experience on each machine. Although subjects in the present study had previous exercise experience on both modalities, which was required to reduce the effects of learning on exercise performance, a pre-study questionnaire revealed that the subjects liked the treadmill more than the elliptical trainer. This bias may have affected their perception of intensity. In future research, exercise preference should be examined to determine if favoritism toward one machine might affect perceived exertion, and therefore, exercise performance.

In summary, the various methodologies used in elliptical trainer research makes comparison among studies difficult. Future research is needed to compare the different models of the elliptical trainer, particularly the effect of the movable arm component on RPE and EE. Another problem in comparing studies is that the subjects in the studies had various fitness and experience levels. Differences in fitness and experience may have affected the subjects' ability to gauge RPE on the various types of equipment. Nevertheless, the treadmill did elicit greater EE than the elliptical trainer at various exercise intensities from the subjects in this study. Since these subjects were trained and experienced with the elliptical trainer, these results may not apply to sedentary individuals or people with limited experience on the elliptical trainer.

Percentage of Machine specific VO_{2max} and HR_{max}

Since subjects in the present study had a lower VO_{2max} and HR_{max} on the elliptical trainer than the treadmill, the percentage of machine specific VO_{2max} and HR_{max} were calculated at each exercise intensity to determine if these varied as well. It was found that there were no significant differences in percentage of machine specific VO_{2max} and HR_{max} between the elliptical trainer and treadmill at moderate (RPE 13) and hard (RPE 15) intensities. These data agree with data from Monya et al. (2001), who also found no difference in the percentage of machine specific VO_{2max} and HR_{max} across six modalities and three intensities. Based on the collective data from Monya et al. and the present study, it would appear that the perception of intensity may be more related to the percentage of machine specific VO_{2max} and HR_{max} as opposed to absolute submaximal VO_2 and HR, which vary across modalities and intensities.

Gender Differences in Submaximal Exercise

An equal number of males and females were selected for the present study to examine gender differences and, as expected, males had a higher absolute submaximal VO_2 than females for both modalities across the three RPE-gauged exercise intensities. When submaximal VO_2 was expressed relative to body weight, males still had a higher submaximal VO_2, which indicates that the difference in VO_2 between the genders was greater than the difference in mass. Since VO_2 is directly proportional to EE, males also obtained higher absolute and relative EE than females at each RPE-gauged intensity of exercise. These data agree with the literature (Kravitz et al., 1997; Moyna et al., 2001; Zeni et al., 1996).

The present study found no gender difference in submaximal HR at the three intensities for both modalities. In contrast, Kravitz et al. (1997) found that females had a significantly higher submaximal HR than males across the studied modalities and intensities. Since the authors believed that the genders interpreted exercise intensity similarly, they attributed the differences in submaximal HR to a lower stroke volume in females. Moyna et al. (2001) found that at a given RPE females had a higher submaximal HR on the rowing ergometer than males, but a lower submaximal HR on the cross-country skier and stepper; both genders had similar submaximal HR on the treadmill, cycle ergometer, and aerobic rider. Since neither study included the elliptical trainer, a direct comparison with the present study is difficult.

Practical Applications

The results of this study are important to people that have the option of exercising on a treadmill or an elliptical trainer as part of a weight loss program. Many such individuals may choose the elliptical trainer because its low impact nature increases user comfort relative to the higher impact treadmill. Data from this study show, however, that the treadmill elicits a greater EE than the elliptical trainer at any given RPE. At a moderate exercise intensity (RPE 13), for example, the average EE on the treadmill was 13.2 $kcal \cdot min^{-1}$, a value that is approximately 15% higher than the 11.3 $kcal \cdot min^{-1}$ burned on the elliptical trainer. Over a 30 minute workout, therefore, 396 kcal will be expended on the treadmill compared to only 339 kcal on the elliptical trainer, a 57 kcal difference. Over the course of one week, if it includes 5 workouts, exercising on the treadmill will burn an additional 285 kcal relative to the elliptical trainer, which will lead to better weight management. This difference, however, is not as great as the difference between the cycle ergometer and the treadmill (Moyna et al. 2001).

Although the elliptical trainer does not maximize EE for a given RPE, it can still provide an adequate workout. The minimal impact of the elliptical can be of great importance for someone with joint or foot concerns. Likewise, obese individuals may have a greater EE on the elliptical trainer than the treadmill (Kim 1999). The elliptical trainer, moreover, can be used in conjunction with the treadmill during training programs to prevent overuse injuries associated with the constant pounding of running. When prescribing exercise on the elliptical trainer, it is important to focus on the cadence and resistance settings. A comfortable combination of these settings should provide an excellent workout and may be essential to clients in clinical settings.

Summary

The primary purpose of this study was to compare the treadmill and the elliptical trainer in terms of EE at three RPE-gauged intensities. Treadmill exercise elicited a greater EE than the elliptical trainer at the three intensities for both genders. Elliptical trainer exercise may have caused more localized leg fatigue than the treadmill, which may lead to a higher perception of intensity at a lower workload relative to the treadmill. Consequently, EE was reduced. The increased localized leg fatigue could have been due to movement patterns and type of muscle contractions elicited by the elliptical trainer. There were no gender differences between modalities, and as expected, males had a higher EE for both modalities across all intensities. Despite the EE differences in modalities, the elliptical trainer still can provide an adequate workout for people who are concerned with weight management.

Chapter 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to compare physiological responses during elliptical trainer and treadmill exercise at three intensities gauged using RPE. In comparing modalities it is important to determine the machine that elicits the greatest EE with the least amount of perceived effort; hence, RPE was selected to gauge intensity. Twenty-four physically active males (n = 12) and females (n = 12) volunteered for the study. Each subject completed maximal and submaximal exercise sessions on both modalities. The maximal tests were used to obtain machines specific VO_{2max}, HR_{max}, and RPE_{max} measurements. The submaximal exercise sessions, which followed 48 h after maximal testing, consisted of three 6-min exercise bouts at RPE-gauged intensities of 11 (fairly light), 13 (somewhat hard) and 15 (hard) on each modality. Prior to all sessions, RPE was explained from a standard set of instructions. Each subject's RPE intensity and modality order was pre-assigned in a partially randomized, balanced fashion.

Three 2 x 2 ANOVA comparing mode and gender for the dependent variables VO_{2max}, HR_{max}, and RPE_{max} revealed that the treadmill elicited a greater VO_{2max} and HR_{max} than the elliptical trainer ($p < 0.05$), but a similar RPE_{max}. Localized leg fatigue and design of elliptical trainer maximum test protocol may have contributed to the modality differences in VO_{2max} and HR_{max}. As expected, males had a higher VO_{2max} than females, which is primarily due to body size and composition. Submaximal exercise data were analyzed using 2 x 2 x 3 ANOVA comparing mode, gender, and RPE intensity level and showed the treadmill elicited greater submaximal VO_2, HR, and EE across the three RPE-gauged intensities ($p < 0.05$).

There were no modality-related gender differences observed. Movement patterns and degree to which eccentric and isometric contractions are involved with each exercise modality may affect perception of intensity. It was expected the elliptical trainer would be comparable to the treadmill in caloric expenditure, because both use similar large muscle groups and have a similar motion. However, the elliptical trainer is similar to the cycle ergometer as both require a person to push a set resistance in a circular motion, which could cause excessive leg fatigue and thereby falsely elevate RPE and lower EE.

Conclusions

The results of this study yielded the following conclusions:

1. The treadmill elicits a greater VO_{2max} and HR_{max} than the elliptical trainer for both genders. Caution should be exercised when determining a true maximum VO_2 from elliptical trainer testing.
2. The treadmill elicits a greater submaximal VO_2, HR and EE across the three RPE-gauged intensities. Given the limitations of this study, it appears the treadmill will result in about 15% more calories expanded than the elliptical trainer for a given perceived effort.

Recommendations

The following recommendations for further study were made after the completion of this investigation:

1. To further understand maximal exercise limitation differences associated with the treadmill and elliptical trainer, leg fatigue should be more closely assessed and BLC should be measured.
2. To better understand the role of leg fatigue influence on RPE, a study should be designed that closely monitors leg discomfort on various modalities and its impact on RPE.
3. Further research should be completed to compare physiological response of the various types of elliptical trainers. This also includes examining elliptical trainers with and without the movable upper body component.
4. Further research should be completed to examine the differences between the elliptical trainer and other modalities, including the stationary bike, cross country ski machine, stepper, and rowing ergometer.
5. Further research should examine the use of different types of subjects, including people who are physically inactive and obese.

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APPENDIX A

PAR – Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	2. Do you feel pain in your chest when you do physical activity?
☐	☐	3. In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☐	☐	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7. Do you know of <u>any other reason</u> why you should not do physical activity?

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want - as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active - begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal - this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

DELAY BECOMING MUCH MORE ACTIVE:

- If you are not feeling well because of temporary illness such as a cold or a fever – wait until you feel better; or
- If you are or may be pregnant – talk to your doctor before you start becoming more active.

Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Name: ______________________________

Signature: ______________________________ Date: ____________

APPENDIX B
INFORMED CONSENT FORM

Comparison of Energy Expenditure between Treadmill and Elliptical Trainer

Purpose of Study

The purpose of this study is to compare energy expenditure between the treadmill and elliptical trainer at selected submaximal intensities.

Benefits of Study

There are benefits for both you and research community from this study. You can benefit by learning your VO_{2max}. The research community can possibly benefit from this study by learning if there is a perceptual difference between the treadmill and elliptical trainer. Exercise specialist could also use the results in a practical manner when prescribing aerobic exercise to a client. If one machine were better than another was, this one would be more commonly prescribed. This can also be beneficial in your own exercise program learning how you perform on each machine.

What You Will Be Asked to Do

First, you will be asked to attend an orientation meeting where you will be described in detail the procedure of the study. At this meeting you will fill out a health history questionnaire and machine use questionnaire and also be allowed to ask questions about the study. This meeting will take 30 minutes.

Following this your participation will take place on 4 separate days. Two of these days will be with the treadmill and other two will be with the elliptical. Each machine has a maximal trial and a submaximal trial separated by at least 48 hours. The maximal and submaximal trials for each machine are separated by at least 7 days. The maximal trial on each modality will take place in the either the Ithaca College Exercise Physiology Laboratory or the Wellness Clinic and should last about 30 minutes. This trial consists of exercising on a treadmill or elliptical trainer until you fatigue, at which point the test will cease. Heart rate and VO_2 will be recorded using a heart rate monitor and a metabolic cart.

The submaximal trial will consist of 3 submaximal runs on either the treadmill or elliptical trainer. Each of these runs will last 6 minutes with 15 minute breaks in between. This session should take about an hour. Again heart rate and VO_2 will be recorded.

Risks

As with all exercise there is always a risk for injury. This risk is even greater during a maximal exercise test. Allowing you to participate only after the primary investigator has cleared you will hopefully minimize any risks. In addition, muscle soreness will likely occur after each trial, however since you do exercise frequently, this should problem should be minimized. This muscle soreness, if any, should last only a few days.

Initial Here___________

If you would like more information about the study

If you would like more information before, during or after the study please feel free to contact Brian Wallace at (607)-272-4378 or e-mail at bwallac1@ic3.ithaca.edu

Withdrawal from the Study

Participation in this study is strictly voluntary; you may withdrawal at any time during the testing procedure. You may omit answers to the questionnaire if you feel uncomfortable answering them. If you do withdrawal, I ask for prior notification if at all possible.

How the Data will be Maintained in Confidence

Information from this study will be maintained in complete confidence. Only the primary investigators will have any access to the information. A subject ID number will be assigned to you to help ensure confidentiality. Participant of the study will not be identified in any data summaries that are made available to other subjects or in any further publication derived from this study.

Participant's Statement

I have read and understood the Informed Consent Document and hereby give my consent for participation in this investigation. I acknowledge that I am 18 years of age or older.

____

Print Name

________________________________ ___________________________

Signature Date

APPENDIX C

EXERCISE PREFERENCE QUESTIONNAIRE

1. When exercising aerobically (i.e. running), how would you rate each of these modalities in terms of most favorable and least favorable (Please circle appropriate number)

Running Overground:	1	2	3	4	5	N/A
Treadmill	1	2	3	4	5	N/A
Elliptical Trainer	1	2	3	4	5	N/A
Stepper	1	2	3	4	5	N/A
Ski Machine	1	2	3	4	5	N/A
Bike (stationary)	1	2	3	4	5	N/A
	(Least Favorable)				(Most Favorable)	

2. If you had a preference between the treadmill and the elliptical trainer, how would you rate your desire to use one over the other

Treadmill	1	2	3	4	5	Elliptical Trainer
			(both machines are adequate)			

3. Do you have any additional comments about your preference on exercise machines?

APPENDIX D

TREADMILL MAXIMAL TRIAL DATA SHEET

Subject ID:_________ Weight (lbs):_______ Speed (mph):_______

STAGE	HR	RPE
1		
2		
3		
4		
5		
6		
7		
8		
9		

VO_{2max} (ml O_2/min/kg):_________________

Max HR:__________

Time to max:_____________

Comments:

APPENDIX F

TREADMILL SUBMAXIMAL TRIAL DATA SHEET

Subject ID:________ Weight (lbs):_______

Trial 1

RPE________ Speed (mph):_______ Incline:___________

Steady State

VO_2:________

Time	HR	Time	HR
:30		4:30	
1:00		5:00	
1:30		5:30	
2:00		**6:00**	
2:30		6:30	
3:00		7:00	
3:30		7:30	
4:00		8:00	

Trial 2

RPE________ Speed (mph):_______ Incline:___________

Steady State

VO_2:________

Time	HR	Time	HR
:30		4:30	
1:00		5:00	
1:30		5:30	
2:00		**6:00**	
2:30		6:30	
3:00		7:00	
3:30		7:30	
4:00		8:00	

Trial 3

RPE________ Speed (mph):_______ Incline:___________

Steady State

VO_2:________

Time	HR	Time	HR
:30		4:30	
1:00		5:00	
1:30		5:30	
2:00		**6:00**	
2:30		6:30	
3:00		7:00	
3:30		7:30	
4:00		8:00	

APPENDIX E

ELLIPTICAL TRAINER MAXIMAL TRIAL DATA SHEET

Subject ID:________ Weight (lbs):_______ Cadence (RPM):__________

STAGE	HR	RPE
1		
2		
3		
4		
5		
6		
7		
8		
9		

VO_{2max} (ml O_2/min/kg):________________

Max HR:__________

Time to max:_____________

Comments:

APPENDIX G
ELLIPTICAL TRAINER SUBMAXIMAL TRIAL DATA SHEET

Subject ID:_________ Weight (lbs):_______

Trial 1

RPE________ Cadence (RPM):_____ Incline:______ Resistance:_________

Steady State

VO_2:________

Time	HR	Time	HR
:30		4:30	
1:00		5:00	
1:30		5:30	
2:00		**6:00**	
2:30		6:30	
3:00		7:00	
3:30		7:30	
4:00		8:00	

Trial 2

RPE________ Cadence (RPM):_____ Incline:______ Resistance:_________

Steady State

VO_2:________

Time	HR	Time	HR
:30		4:30	
1:00		5:00	
1:30		5:30	
2:00		**6:00**	
2:30		6:30	
3:00		7:00	
3:30		7:30	
4:00		8:00	

Trial 3

RPE________ Cadence (RPM):_____ Incline:______ Resistance:_________

Steady State

VO_2:________

Time	HR	Time	HR
:30		4:30	
1:00		5:00	
1:30		5:30	
2:00		**6:00**	
2:30		6:30	
3:00		7:00	
3:30		7:30	
4:00		8:00	

APPENDIX H

Raw Data

Table H1

Descriptive raw data

Subject ID	Gender	Height (cm)	Age (y)	Weight (kg)	First Modality	RPE Order
1	F	160	20	58.2	TR	11, 13, 15
2	M	183	21	82.7	ET	15, 13, 11
3	F	160	22	55.0	TR	13, 11, 15
4	M	165	22	70.5	TR	13, 11, 15
5	F	173	21	70.0	ET	13, 11, 15
6	F	160	21	50.9	ET	15, 13, 11
7	M	196	22	90.9	ET	13, 11, 15
8	M	183	22	79.5	ET	11, 15, 13
9	F	173	21	75.0	TR	11, 15, 13
10	F	173	22	70.5	TR	13, 15, 11
11	F	168	20	61.4	TR	15, 11, 13
12	M	193	21	81.4	TR	11, 15, 13
13	F	157	23	68.2	ET	11, 13, 15
14	F	165	22	70.5	ET	13, 15, 11
15	M	165	18	63.6	TR	11, 13, 15
16	F	160	18	61.4	ET	11, 15, 13
17	F	170	18	65.9	ET	15, 11, 13
18	F	160	19	59.1	TR	15, 13, 11
19	M	185	22	88.6	ET	11, 13, 15
20	M	183	21	89.5	TR	13, 15, 11
21	M	196	21	88.6	TR	15, 13, 11
22	M	193	21	77.3	ET	15, 11, 13
23	M	178	28	71.4	TR	15, 11, 13
24	M	191	23	85.0	ET	13, 15, 11

Note: TR = treadmill and ET = elliptical trainer.

Table H2

Raw data from mode preference questionnaire

Subject ID	Q. 1A	Q. 1B	Q. 1C	Q. 1D	Q. 1E	Q. 1F	Q. 2
1	1	4	3	5	3	1	2
2	4	4	2	3	6	3	2
3	5	3	1	5	1	3	1
4	4	5	4	3	6	4	1
5	5	3	4	2	1	3	4
6	5	4	4	3	6	5	2
7	3	3	5	4	4	4	4
8	5	4	3	1	1	3	1
9	5	4	3	4	6	3	2
10	5	5	4	3	1	3	2
11	5	4	2	1	6	5	1
12	5	4	3	3	3	5	2
13	3	2	5	1	1	5	4
14	4	3	4	1	6	1	4
15	4	5	4	3	1	4	2
16	5	3	3	4	6	1	3
17	3	2	5	2	2	2	5
18	5	3	2	3	1	4	2
19	4	4	3	5	6	3	2
20	1	2	5	3	3	4	5
21	5	3	2	1	2	4	2
22	3	1	5	3	1	2	5
23	5	3	1	6	6	4	1
24	5	3	3	4	2	2	2

Note: Q. = Question.

Table H3

Raw data from maximal treadmill session

Subject ID	Speed (mph)	Time (min:s)	VO_{2max} (ml·min^{-1}·kg^{-1})	HR_{max} (bpm)	RPE_{max}
1	6.0	09:30	47.3	203	17
2	7.0	10:55	58.4	197	17
3	6.4	10:00	48.5	209	17
4	7.5	09:30	49.6	197	16
5	6.0	10:00	43.7	178	19
6	6.0	12:45	50.6	196	18
7	7.0	10:00	49.0	192	19
8	7.0	10:30	63.4	191	18
9	6.5	10:00	43.6	179	17
10	6.5	08:00	41.6	182	17
11	7.0	10:00	53.4	200	18
12	7.5	13:30	61.8	218	17
13	6.0	06:00	41.3	181	17
14	6.0	08:00	40.9	190	17
15	7.0	12:15	55.1	188	16
16	6.0	08:00	44.3	181	18
17	6.0	09:00	41.8	192	16
18	6.0	14:00	53.1	198	19
19	6.5	12:30	47.4	190	19
20	6.0	10:30	46.6	191	19
21	6.9	15:00	56.0	192	17
22	6.0	10:00	48.7	179	19
23	6.5	14:00	62.9	194	19
24	7.0	11:00	59.5	192	17

Table H4

Raw data from elliptical trainer maximal session

Subject ID	Cadence (rpm)	Time (min:s)	VO_{2max} ($ml \cdot min^{-1} \cdot kg^{-1}$)	HR_{max} (bpm)	RPE_{max}
1	180	12:00	41.3	198	17
2	180	16:00	50.9	194	17
3	185	10:00	44.3	202	17
4	180	12:00	45.4	182	16
5	160	13:30	42.0	172	16
6	185	12:30	47.1	196	17
7	200	15:00	48.0	192	18
8	185	14:00	46.2	179	18
9	180	13:15	42.7	174	16
10	180	12:00	37.8	192	18
11	190	11:45	43.4	182	18
12	200	16:00	56.7	210	19
13	170	11:30	40.4	188	17
14	170	13:00	38.9	182	16
15	200	14:30	54.0	180	17
16	160	13:30	41.6	182	16
17	180	12:45	41.5	189	17
18	180	13:45	46.7	185	16
19	200	14:30	46.4	189	18
20	180	12:00	41.5	181	17
21	200	16:30	51.4	187	19
22	200	14:00	46.3	178	18
23	200	11:00	49.8	185	19
24	200	12:30	51.0	187	18

Table H5

Raw data for submaximal treadmill session at RPE 11

Subject ID	Speed (mph)	Incline (% Grade)	VO_2 (ml·min^{-1}·kg^{-1})	% MS VO_{2max}	HR (bpm)	% MS HR_{max}	EE (kcal·min^{-1})
1	5.4	0	31.2	65.96	174	85.71	9.05
2	7.0	0	40.1	68.66	176	89.34	16.45
3	6.6	0	36.6	75.46	180	86.12	9.91
4	6.9	0	35.1	70.77	167	84.77	12.31
5	5.7	0	25.6	58.58	134	75.28	8.78
6	5.1	0	28.0	55.34	149	76.02	7.05
7	6.5	0	32.6	66.53	162	84.38	14.59
8	7.5	0	36.6	57.73	156	81.68	14.69
9	6.3	1	33.0	75.69	146	81.56	12.37
10	5.2	0	25.3	60.82	148	81.32	8.85
11	6.5	0	34.0	63.67	175	87.50	10.23
12	5.1	0	28.0	45.31	125	57.34	11.19
13	5.2	0	30.7	74.33	156	86.19	10.46
14	4.6	0	23.7	57.95	156	82.11	8.21
15	6.6	0	30.0	54.45	135	71.81	9.44
16	4.4	0	24.9	56.21	132	72.93	7.62
17	4.6	0	24.2	57.89	153	79.69	7.87
18	4.4	0	21.2	39.92	138	69.70	6.18
19	6.8	3	37.4	78.90	161	84.74	16.72
20	4.8	0	27.0	57.94	151	79.06	11.90
21	5.7	4	33.3	59.46	134	69.79	14.64
22	4.9	0	29.2	59.96	137	76.54	11.06
23	5.5	0	32.8	52.15	148	76.29	11.41
24	6.0	0	33.3	55.97	157	81.77	13.87

Note: MS = machine specific.

Table H6

Raw data for submaximal treadmill session at RPE 13

Subject ID	Speed (mph)	Incline (% Grade)	VO_2 ($ml \cdot min^{-1} \cdot kg^{-1}$)	% MS VO_{2max}	HR (bpm)	% MS HR_{max}	EE ($kcal \cdot min^{-1}$)
1	6.9	0	41.8	88.37	190	93.60	12.28
2	8.2	0	47.8	81.85	185	93.91	19.61
3	7.7	0	40.3	83.09	188	89.95	11.19
4	7.4	0	34.9	70.36	166	84.26	12.36
5	6.6	0	29.9	68.42	151	84.83	10.25
6	6.2	1	31.6	62.45	159	81.12	7.96
7	7.3	1	38.5	78.57	170	88.54	17.49
8	7.8	0	40.7	64.20	168	87.96	16.33
9	7.3	1	32.1	73.62	169	94.41	11.97
10	6.2	0	30.3	72.84	159	87.36	10.68
11	7.4	0	39.4	73.78	181	90.50	12.09
12	6.5	0	39.8	64.40	162	74.31	15.71
13	6.6	0	35.3	85.47	164	90.61	12.12
14	6.9	0	36.9	90.22	177	93.16	13.13
15	7.7	0	36.5	66.24	152	80.85	11.60
16	4.9	0	25.8	58.24	137	75.69	7.90
17	6.6	0	32.5	77.75	172	89.58	10.73
18	5.3	0	24.5	46.14	149	75.25	7.16
19	7.0	5	42.7	90.08	177	93.16	19.09
20	5.6	0	30.0	64.38	159	83.25	13.45
21	6.1	5	39.1	69.82	140	72.92	17.23
22	5.8	3	38.4	78.85	169	94.41	14.73
23	6.9	0	39.4	62.64	164	84.54	13.99
24	8.1	0	41.0	68.91	175	91.15	17.55

Note: MS = machine specific.

Table H7

Raw data for submaximal treadmill session at RPE 15

Subject ID	Speed (mph)	Incline (% Grade)	VO_2 ($ml \cdot min^{-1} \cdot kg^{-1}$)	% MS VO_{2max}	HR (bpm)	% MS HR_{max}	EE ($kcal \cdot min^{-1}$)
1	7.7	0	44.8	94.71	197	97.04	13.16
2	10.1	0	53.1	90.92	193	97.97	22.16
3	8.3	0	44.0	90.72	198	94.74	12.21
4	8.2	0	39.5	79.64	179	90.86	13.85
5	7.2	0	34.2	78.26	163	91.57	11.97
6	6.5	3	38.9	76.88	173	88.27	9.85
7	7.7	2	44.3	90.41	180	93.75	20.32
8	8.8	0	43.9	69.24	172	90.05	17.61
9	7.7	3	41.1	94.27	177	98.88	15.56
10	6.7	0	33.9	81.49	171	93.96	12.00
11	9.2	0	48.1	90.07	194	97.00	14.91
12	7.8	4	48.4	78.32	185	84.86	19.69
13	7.0	0	36.2	87.65	174	96.13	12.46
14	7.1	0	36.3	88.75	181	95.26	12.92
15	8.8	0	42.6	77.31	169	89.89	13.67
16	5.6	0	32.1	72.46	148	81.77	9.83
17	7.1	0	35.3	84.45	178	92.71	11.74
18	6.4	0	30.2	56.87	158	79.80	8.88
19	6.8	8	48.3	100.00	187	98.42	21.60
20	6.5	5	41.3	88.63	180	94.24	18.66
21	6.9	5	40.9	73.04	142	73.96	18.02
22	6.1	4	41.2	84.60	164	91.62	15.96
23	8.3	0	44.9	71.38	180	92.78	16.18
24	8.1	3	47.6	80.00	185	96.35	20.42

Note: MS = machine specific.

Table H8

Raw data for submaximal elliptical trainer session at RPE 11

Subject ID	Cadence (rpm)	Resistance	VO_2 ($ml \cdot min^{-1} \cdot kg^{-1}$)	% MS VO_{2max}	HR (bpm)	% MS HR_{max}	EE ($kcal \cdot min^{-1}$)
1	170	7	28.9	69.98	164	82.83	8.49
2	155	5	22.2	43.61	125	64.43	9.02
3	170	4	32.3	72.91	155	76.73	8.72
4	160	10	37.5	82.60	171	93.96	13.34
5	130	5	15.7	37.38	134	77.91	5.42
6	165	3	23.5	49.89	138	70.41	5.90
7	180	3	25.6	53.33	151	78.65	11.31
8	150	7	22.5	48.70	119	66.48	8.90
9	175	7	26.8	62.76	128	73.56	10.02
10	190	3	26.6	70.37	168	87.50	9.26
11	183	1	25.7	59.22	148	81.32	7.56
12	200	3	30.5	53.79	152	72.38	12.25
13	160	4	21.8	53.96	134	71.28	7.34
14	150	4	18.5	47.56	137	75.27	6.41
15	180	5	26.1	48.33	125	69.44	8.08
16	170	0	22.7	54.57	121	66.48	6.88
17	160	5	22.0	53.01	141	74.60	7.23
18	185	3	23.0	49.25	135	72.97	6.84
19	200	7	27.2	58.62	138	73.02	12.10
20	160	3	19.5	46.99	123	67.96	8.72
21	180	3	24.8	48.25	119	63.64	10.71
22	190	6	25.2	54.43	129	72.47	9.64
23	190	4	29.6	59.44	152	82.16	10.43
24	175	3	17.5	34.31	122	65.24	7.23

Note: MS = machine specific.

Table H9

Raw data for submaximal elliptical trainer session at RPE 13

Subject ID	Cadence (rpm)	Resistance	VO_2 ($ml \cdot min^{-1} \cdot kg^{-1}$)	% MS VO_{2max}	HR (bpm)	% MS HR_{max}	EE ($kcal \cdot min^{-1}$)
1	193	8	36.4	88.14	180	90.91	10.69
2	170	10	34.7	68.17	159	81.96	14.27
3	180	4	40.4	91.20	156	77.23	11.19
4	170	10	41.6	91.63	172	94.51	14.80
5	160	6	22.2	52.86	134	77.91	7.57
6	185	10	31.6	67.09	168	85.71	7.82
7	190	7	30.3	63.13	162	84.38	13.43
8	150	12	32.0	69.26	140	78.21	12.81
9	185	9	32.4	75.88	153	87.93	12.06
10	190	6	29.3	77.51	163	84.90	10.35
11	190	6	30.6	70.51	167	91.76	9.30
12	200	7	34.7	61.20	172	81.90	13.94
13	150	9	27.3	67.57	156	82.98	9.26
14	157	8	24.5	62.98	156	85.71	8.67
15	195	7	32.1	59.44	139	77.22	10.10
16	170	6	28.7	68.99	143	78.57	8.74
17	180	5	23.2	55.90	149	78.84	7.64
18	200	4	25.6	54.82	142	76.76	7.64
19	200	10	37.4	80.60	163	86.24	16.72
20	160	6	24.8	59.76	132	72.93	11.20
21	170	11	33.9	65.95	146	78.07	14.94
22	193	8	29.4	63.50	139	78.09	11.30
23	200	6	32.2	64.66	158	85.41	11.58
24	220	8	33.2	65.10	157	83.96	14.21

Note: MS = machine specific.

Table H10

Raw data for submaximal elliptical trainer session at RPE 15

Subject ID	Cadence (rpm)	Resistance	VO_2 ($ml \cdot min^{-1} \cdot kg^{-1}$)	% MS VO_{2max}	HR (bpm)	% MS HR_{max}	EE ($kcal \cdot min^{-1}$)
1	195	9	41.9	100.00	194	97.98	12.31
2	170	11	36.4	71.51	160	82.47	15.19
3	180	10	45.7	103.16	189	93.56	12.69
4	150	13	43.5	95.81	183	100.00	15.48
5	160	8	29.8	70.95	152	88.37	10.22
6	165	10	46.3	98.30	191	97.45	11.89
7	185	9	31.8	66.25	166	86.46	14.16
8	150	12	36.9	79.87	148	82.68	14.73
9	190	10	35.9	84.07	157	90.23	13.59
10	190	8	33.5	88.62	178	92.71	11.77
11	175	10	40.4	93.09	173	95.05	12.52
12	220	9	42.7	75.31	182	86.67	17.03
13	147	10	28.0	69.31	166	88.30	9.52
14	180	9	33.2	85.35	183	100.00	11.81
15	200	10	43.3	80.19	164	91.11	13.90
16	170	8	32.0	76.92	154	84.62	9.92
17	170	8	31.1	74.94	165	87.30	10.32
18	195	6	29.0	62.10	149	80.54	8.65
19	195	13	45.7	98.49	176	93.12	20.44
20	150	7	26.7	64.34	143	79.01	12.06
21	160	13	42.5	82.68	155	82.89	18.96
22	195	9	33.5	72.35	147	82.58	12.91
23	185	11	46.5	93.37	178	96.22	16.76
24	230	9	39.2	76.86	173	92.51	16.82

Note: MS = machine specific.