A Physiological and Subjective Comparison of the ElliptiGO and Running in Highly Fit Trained Runners

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This thesis titled
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Abstract

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A Physiological and Subjective Comparison of the ElliptiGO and Running in Highly Fit Trained Runners

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Runners exhibit high injury rates from running. To avoid detraining, cross-training methods are implemented in order to maintain fitness and performance in trained fit runners. Many current cross-training methods have been unable to maintain prior physiological and performance levels and also present subjective differences to running. The ElliptiGO bicycle is a new form of cross-training that aims to provide a low impact, running specific, high intensity exercise experience. This project aimed to compare physiological variables, run performance and subjective variables following ElliptiGO training (ET) and run training (RT). This study displayed maintenance of physiological variables following the ET. Furthermore, run performance was not significantly different following the ET period. Subjectively the ElliptiGO provided a similar experience compared to running for enjoyment, soreness and effort levels.
This thesis is dedicated to God for closing doors in my life and opening ones to better opportunities to glorify Him. I thank Him for the amazing mentors, friends and those who have supported and encouraged my pursuit of this project. “Rejoice always, pray continually, give thanks in all circumstances; for this is God’s will for you in Christ Jesus.” 1 Thes 5:16-18.
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Chapter 1: Introduction

Exercise has long been found to be beneficial for one’s health (Blair et al., 1995; Eriksson, 1986). Distance running is one of the most popular forms of exercise with over 15 million race finishers as of 2012 (Running USA, 2014). Running durations, frequencies, and intensities are systematically manipulated by a runner or coach in order to maximize the physiological training adaptations and subsequently running performance for a particular race distance. In order to quantify the effects of these training adaptations on endurance fitness and performance, factors predicting distance runners’ endurance performance are measured and evaluated for their independent and collective benefit (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999). Maximal oxygen consumption (VO$_2$max), anaerobic threshold (AT), and running economy (RE) have been found to be strong physiological predictors of endurance performance in highly fit, competitive runners (Foster & Lucia, 2007; Jones & Carter, 2000; McLaughlin, Howley, Bassett, Thompson, & Fitzhugh, 2010). It has long been known that repeated training bouts over a period of time can improve these factors (Daniels, Yarbrough, & Foster, 1978). Ultimately, run training that includes increasing the training volume beyond a runner’s training threshold too often or too quickly without adequate recovery can lead to injury (Brody, 1980). It is reported that 37-79% of runners have experienced a running-related injury within a 1 year span (Mechelen, 1992; van Gent et al., 2007). The most common running injuries in the lower extremity occur to the feet, hips, and predominantly the knees (van Middelkoop, Kolkman, Ochten, Bierma-Zeinstra, & Koes, 2008). Furthermore, overuse injuries are prevalent among competitive runners due to the
increased training volumes and other training errors that can lead to injury (Wilder & Sethi, 2004).

Any type of injury can cause a partial or full termination of run training. Detraining or the reversibility of training adaptations can occur when there is a cessation or decrease in running volume and can also lead to a decline in physiological adaptations and performance measures (Mujika & Padilla, 2000). To attenuate these detrimental losses, runners often participate in cross-training (Tanaka, 1994). Cross-training methods encompass any alternative form of exercise implemented into a runner’s training program apart from running. Only deep water running (DWR) has been seen to maintain fitness and performance measures in highly fit runners following 4 and 6 week training periods (Bushman et al., 1996; Wilber, Moffatt, Scott, Lee, & Cucuzzo, 1996). Attempting to remain as running specific as possible, DWR is designed to replicate the running motion in deep water and could explain the observed maintenance of fitness and performance compared to cross-training methods, such as swimming and cycling, which do not incorporate a similar running motion.

Following this principle of specificity, a new form of cross-training, the ElliptiGO bicycle (Outdoor Elliptical Bikes–ElliptiGO, 2014), has been developed for runners to emulate running while reducing impact. The ElliptiGO bicycle is a combination of an elliptical trainer and a bicycle, on wheels, with modifications to closely emulate the running motion in order to elicit running-specific training adaptations. These modifications include an increased stride length, greater knee flexion during the recovery stroke, and the absence of a fly wheel compared to traditional elliptical trainers.
Currently, there are no peer-reviewed research articles which have investigated the running-specific claims of the ElliptiGO. Research using the ElliptiGO bicycle would provide insight into the effectiveness of the ElliptiGO bicycle as a cross-training option for maintaining or improving physiological factors and endurance performance in the large running population.

**Statement of Problem**

The high incidence of injury due to high impact running is significant reason to investigate the ElliptiGO bicycle as a cross-training modality for the runner population. The ElliptiGO bicycle is marketed as the closest type of exercise to running with low impact forces. There are no current published research articles investigating the effects of chronic exercise training using the ElliptiGO bicycle.

**Purpose**

The purpose of this study was to investigate the physiological and subjective responses to a 4-week training program using an ElliptiGO bicycle compared to a matched run-training program.

**Significance**

Knowledge of the effectiveness of the ElliptiGO bicycle on running performance will benefit the running community, healthcare professionals, trained athletes, coaches, injury-limited exercisers, and the research community by validating the use of the ElliptiGO bicycle as an effective cross-training modality for runners. Understanding the physiological response to training using an ElliptiGO bicycle will be beneficial in order to utilize this machine during periods of rehabilitation or as supplementary training in a...
runner’s training program. Subjective data, such as soreness, enjoyment, and effort levels, could also prove beneficial for these populations in establishing the ElliptiGO bicycle as an overall better cross-training modality, both physically and psychologically.

**Delimitations**

The following were delimitations for this study:

1. Participants were 18-35 year old runners with previous running experience residing in Southeastern, OH.

2. Healthy participants were determined by measuring body fat, anthropometric data, and through a health history questionnaire (see Appendix II). Participants were free of exercise-limiting disease or injury.

3. Participants were required to follow a prescribed training protocol and were not allowed to perform any other moderate to vigorous intensity exercise that might alter training adaptations or limit recovery.

4. Participants were highly fit as determined by maximal oxygen consumption attained during a graded exercise test.

5. Participants read and signed a human consent form before participating in this study.

6. The Institutional Review Board at Ohio University approved this study.

**Limitations**

1. Participants were not continuously monitored, thus researchers were unable to ensure participants abstained from exercise or other vigorous activities outside the training protocol.
2. Researchers were unable to control the effects of diet and use of recovery methods, which might have varied among participants.

3. A participant’s training sessions took place at various times of the day when the participant was available to train. Researchers were unable to control for weather, environmental, or other external factors that might have impacted physiological, performance, and subjective values.

4. Medical issues or conditions that cause changes in physiological responses or ratings of perceived effort (RPE) values were not controlled.

Assumptions

The following assumptions were made for this study:

1. Information provided by each participant was considered as true and no information was fabricated or falsified.

2. Participants followed the training protocol and did not alter their daily activities in a way that could have impacted the results.

3. Exercise prescription was dependent upon the participant’s ability to provide a maximum effort during the maximal oxygen consumption tests.

4. Participants were able to abstain from alcohol and exercise at least 24 hours before testing.

Hypothesis

The hypotheses for this study were:

1. There will be no difference in running performance factors: VO$_2$max, anaerobic
threshold, running economy, or 5,000 m time trial run time, between the
ElliptiGO and run training group.

2. There will be no difference in running performance factors: VO₂ max, anaerobic
threshold, running economy, or 5,000 m run time trial time, within either the
ElliptiGO or run training groups following either training period.

3. There will be no difference between subjective variables, including ratings of
perceived effort, enjoyment, and soreness, values between the ElliptiGO and the
run group.

Definition of Terms

**Aerobic capacity.** An individual’s maximum ability to transport and utilize
oxygen within the body.

**Anaerobic threshold (AT).** The intensity or workload when the anaerobic energy
systems provide the majority of energy needs for given intensity.

**Antigravity treadmills.** Specially designed treadmills with an apparatus that
allows individuals to run at a percentage of their body weight.

**Body mass index (BMI).** A calculation that categorizes an individual as
underweight, normal, overweight, or obese based on a ratio of height in meters squared
divided by weight in kilograms.

**Borg’s rating of perceived exertion (RPE).** The level of whole body effort on a
scale of six to twenty. This effort rating scale can also be taken on upper and lower
sections of the body.

**Cross-training.** The use of an exercise modality that differs from an individual’s
sport specific training modality (i.e. a competitive runner can cross-train by swimming or biking).

**Deep water running (DWR).** An exercise modality described as running while wearing a flotation device in water deep enough to suspend individuals without making contact with the ground.

**Detraining.** The loss of training adaptations or physiological ability during cessation or reduction in exercise stimulus.

**Elliptical cross-trainer.** A low impact exercise machine where the individual’s feet travel through an ellipse shape with optional push-pull arm handles.

**ElliptiGO bicycle (EPTGO).** A mobile outdoor elliptical-like cross-trainer with front and back wheels, handlebars, and gears as found on a bicycle, that emulates the running motion.

**Energy expenditure (EE).** The total number of calories expended.

**Exercise volume.** The combination of exercise duration, frequency, and intensity.

**Graded exercise test (GXT).** An exercise test that utilizes stages of increasing intensity in order to elicit maximal physiological responses.

**Lactate threshold (LT).** The intensity or workload when lactate is now accumulating at a faster rate than lactate is being cleared from the muscle. LT is used to estimate AT.

**Maximal oxygen consumption (VO₂ max).** The body’s ability to maximally transport and utilize oxygen and is a measurement of physical fitness.

**Respiratory exchange ratio (RER).** A ratio calculated by dividing ventilated
carbon dioxide ($\text{VCO}_2$) by the ventilated oxygen ($\text{VO}_2$) in order to determine the energy utilization.

**Respiratory compensation point (RCP).** The second breaking point in the rise of the slope lines of VE/VO$_2$ with a continued plateau of VE/VCO$_2$.

**Running economy (RE).** A measurement of an individual’s efficiency while running, measured as a ratio of oxygen consumption (VO$_2$) over running speed (m/s).

**Percent body fat.** A measurement of non-essential fat via a skin fold method.

**Stair climber.** A non-mobile exercise machine that emulates the stair walking experience.

**Street Strider (SS).** A mobile exercise machine modeled to imitate an elliptical cross-trainer consisting of three wheels and push-pull handles.
Chapter 2: Literature Review

General Benefits of Exercise

Physical fitness has been recognized as a predictor of quality of life and probably of mortality for many years. Specifically, low physical fitness is strongly linked to all-cause mortality (Blair et al., 1995). Two physical assessments were performed on 9777 men, including a maximal exercise test and health questionnaire, with an average of 4.9 years (± 4.1) in between examinations. Fit or healthy men were classified by having normal electrocardiograms, during rest and exercise with no history of cardiovascular, metabolic or pulmonary diseases during both examinations. Men with one or more disease conditions were classified as unfit or unhealthy. Unfit men at both examinations had a 44% greater age-adjusted mortality rate compared to men who became fit from the first to second examination (Blair et al., 1995). Overall, men who were fit at both examinations had the lowest all-cause mortality rate. In concordance, a graded response for chronic heart disease mortality in 1,832 men among quartile physical fitness groups was observed (Erikssen, 1986). A decrease in coronary heart disease mortality was seen from low-to-high-fit groups with over 50% of deaths coming from the lowest fit group (Erikssen, 1986). Blood pressure (BP), heart rate (HR), total cholesterol, triglycerides, HDL-C, and Spirograph measures exhibited a similar pattern of most fit to least fit group, with the least fit group having values that indicated being unhealthy. Blair and colleagues (1995) also showed this trend by finding that every 1 minute increase in maximal treadmill time resulted in a 7.9% decrease in risk of mortality. These results indicate a
negative correlation between fitness and mortality, and display the importance of physical
fitness on health factors and risk of mortality.

Exercise Prescription

The American Council of Sports Medicine (ACSM) recommends cardiovascular
exercise prescriptions for the general population in order to maintain a healthy level of
fitness that includes:

. . . moderate intensity aerobic exercise (40% to < 60% VO₂R) done at least 5
days per week, or vigorous intensity aerobic exercise (> 60% VO₂R) done at least
3 days per week, or a combination of 3-5 days per week of moderate and vigorous
intensity exercise is recommended for the majority of adults to achieve and
maintain health/fitness benefits. Exercise durations per session should reach 30
minutes for moderate intensity exercise, 20-25 minutes for vigorous exercise or a
combination of 20-30 minutes for both intensities. (p. 155)

The aforementioned exercise prescriptions are not adequate for competitive
runners who aim to be highly trained or compete in running competitions at high levels.

Because of this, most competitive runners, and other competitive athletes,
increase their volume of training by altering the intensity, duration, and frequency of
training. Intensity is often measured as a percentage of VO₂max or maximal heart rate
(HRmax); duration is presented as time or distance; and frequency can be relayed as the
number of exercise sessions. All these variables can be manipulated in order to improve
one’s aerobic capacity (Davies & Knibbs, 1971; Wenger & Bell, 1986), and coaches and
athletes manipulate these variables in order to gain physiological adaptations specific to
competition demands and to maximize planned performances during running competitions.

Numerous studies and review articles have demonstrated this continued improvement in aerobic capacity due to specific body system adaptations. Predominantly these changes occur in the muscle’s mitochondrial function (Daussin et al., 2008), cardiorespiratory system (Jones & Carter, 2000), and nervous system (Nummeula et al., 2006) when training beyond the recommended ACSM guidelines. The degree of physiological adaptations that would improve endurance performance is dependent on the volume of endurance training (Wenger & Bell, 1986). Thus, in order to compete at high levels, highly trained athletes are constantly aiming to maximize these physiological adaptations through a manipulation of their total training volume. Many physiological factors have been investigated in order to gauge the effects of different training methods on endurance performance. These factors will be discussed in order to validate their use as the best methods for measuring changes in endurance performance in this current study.

**Maximal Oxygen Consumption**

Maximal oxygen consumption (VO\textsubscript{2}\text{max}) was one of the first physiological factors to be investigated as a determinant or predictor of endurance performance in athletes (Saltin & Astrand, 1967). These authors measured the VO\textsubscript{2}\text{max} values of 95 male and 38 female athletes on their respective Swedish National Teams. Endurance sports ranged from bicycling, cross-country skiing, running, and swimming and nonendurance sports of weight lifting, wrestling, gymnastics, and fencing. Endurance sports displayed
higher VO_{2\text{max}} values than nonendurance sports indicating a relationship between higher VO_{2\text{max}} values and endurance performance in national caliber athletes. Similar results by Costill, Thomason, and Roberts (1973) found a strong correlation ($r = -0.91$) between relative VO$_2$max (ml/kg/min) and a 10-mile race in trained distance runners.

The possibility of improving VO$_2$max values has been reviewed in order to understand the potential for maximizing performance by improving it (Jones & Carter, 2000). Endurance training has been effective in improving VO$_2$max values more frequently in lower fit, untrained individuals (Jones & Carter, 2000). Continually, VO$_2$max values were shown to increase due to training in low-fit individuals who became more fit from a cycling exercise program. VO$_2$max values increased 25% in a 9-week endurance cycling training program in formerly sedentary males (Davis, Frank, Whipp, & Wasserman, 1979). These aforementioned studies make strong statements for the possibility of improving VO$_2$max and, thus, endurance performance. However, this degree of improvement was not clearly seen in higher fit and trained athletes in a study of endurance trained male athletes ($n = 8$) undergoing interval training at the intensities observed at the onset blood lactate (OBLA) and VO$_2$max (Billat et al., 1999). It is speculated that as a runner becomes more fit and trained, a ceiling effect occurs with one’s VO$_2$max.

Evidence shows that VO$_2$max was not as strong of a predictor of performance among recreationally trained runners (Daniels et al., 1978). Daniels and colleagues also revealed no significant difference after training for recreationally trained runners. Moreover, although there was a significant improvement in VO$_2$max in untrained,
somewhat conditioned students after the first 4 weeks of training, there was no significant increases following an additional 4 weeks (Daniels et al., 1978). Lastly, a significant performance improvement was seen for both groups for distances of 805 m and 3,218 m. Performances improved 75% and 60% in the first half of this study for the untrained and trained groups, respectively (Daniels et al., 1978). These results indicate that performance might be influenced by other possible factors.

Alternatively, various studies have shown improvements in VO$_2$max following high intensity training in runners. In an investigation using trained, high fit runners, VO$_2$max values were seen to significantly improve after training at velocities equal to the velocity obtained at VO$_2$max (Vmax). The training interval durations were equal to the time it took to reach exhaustion while running at Vmax. Training lasted 4 weeks, including 12 training sessions for approximately 60 minutes each session (Smith, McNaughton, & Marshall, 1999). Results displayed a significant improvement in VO$_2$max and 3,000 m time trial performance following training. The training effects on VO$_2$max were well investigated by Priest and Hagan (1987), who separated runners into experienced and novice groups. These authors saw significant improvements in VO$_2$max values following 7 weeks of maximal steady state (MSS) run training (Priest & Hagan, 1987). Again, the training that was selected was very high intensity (>VO$_2$max intensity) which creates the thought that in order to improve a fit and trained runner’s VO$_2$max, high intensity intervals are needed.

Using an athlete’s VO$_2$max value has been criticized as not being the best determinant when predicting endurance performance in trained athletes. Early studies
have noted that runners were not obtaining higher VO$_2$max values compared to a study performed 30 years prior (Robinson, Edward, & Dill, 1937; Saltin & Astrand, 1967), but the world record two mile holder was 30 seconds faster. Authors suggested that running technique and the ability to run close to maximum anaerobic power were reasons for these improved times without an increase in VO$_2$max. These observations suggest other variables are important in predicting performance.

**Anaerobic Threshold**

Of greater concern for the endurance runner is the ability to run at a submaximal velocity for prolonged periods of time without any decreases in velocity due to fatigue. This velocity most often occurs at a runner’s anaerobic threshold (AT). There is strong evidence to encourage the use of this additional performance factor to predict endurance performance in higher fit athletes (Henritze, Weltman, Schurrer, & Barlow, 1985). AT is commonly referred to as the intensity when the body shifts from producing energy necessary for muscle actions from primarily aerobic energy pathways and begins supplementing energy production to a greater degree from anaerobic pathways. This causes an increase in the concentration of lactic acid and muscle acidity beyond what is tolerable (Wilmore & Costill, 2005).

There have been displayed changes in the oxygen consumption at an athlete’s lactate threshold (VO$_2$LT) and VO$_2$LT/VO$_2$max following a 12-week, high intensity training program (Henritze et al., 1985). Only the above LT group showed improvements in VO$_2$LT (Henritze et al., 1985). Additionally, VO$_2$max did not increase within any group. This study supports the possibility of a VO$_2$max ceiling effect in highly trained
runners whereas physiological factors, such as anaerobic threshold, are dynamic and can be improved with further training. Again, intensity was seen to be a determining factor as to whether improvements were seen. These results indicate the importance of analyzing other physiological variables for endurance performance (Henritze et al., 1985).

Nevertheless, AT has been supported as a better predictor of running performance in trained athletes than VO\(_2\)max (Martin, 1986; Noakes, Myburgh, & Schall, 1990).

A significant increase in the percentage of VO\(_2\)max when AT occurs has been seen in an investigation of elite, male distance runners preparing for the Olympic Games (Martin et al., 1986). Runners had VO\(_2\)max values on average of 79.3 ml/kg/min (± 5.4) with a range of 66.5 to 90.7 ml/kg/min. AT measurements were taken during three training periods: endurance, sharpening, and competitive training periods, averaging 88.2% (± 10.3) of VO\(_2\)max over all periods (Martin et al., 1986). A 5.6% increase in AT was seen from mid-endurance to competitive periods. Additionally, personal records were run during the competitive period. Specific training details were not included in this study, but it was known that high intensity run training was occurring during all three periods (Martin et al., 1986). These findings concur with results from an investigation that observed AT over a 4.5 month period (Tanaka, 1994). A correlation of 0.80 was observed between AT values and 10,000 m race times. Performance predicting variables do exist, as mentioned; however, it is most likely a combination of factors that enables a runner to achieve a high level of performance.

Costill et al. (1973) advanced upon the postulations made by Saltin and Astrand (1967) by measuring the VO\(_2\) and lactate values at set running speeds. When running
speeds of greater than 70% of VO₂max were measured, lactate values were lower in the faster runners based upon 10 mile run times. These results show the importance of using the anaerobic threshold measurement as a means of predicting endurance performance.

**Running Economy**

The third major physiological determinant of running performance is RE, which is defined as the oxygen consumption at a particular running velocity (Saunders, Pyne, Telford, & Hawley, 2004). A high correlation has been shown between a runner’s RE and endurance performance (Conley & Krahenbuhl, 1980). Among highly trained, distance runners there was a low correlation ($r = -0.12$) between VO₂max and running performance, but 65.4% of the variation could be attributed to the differences in running economy in this group (Conley & Krahenbuhl, 1980). This strongly suggests that RE in higher fit, trained runners is a better predictor than VO₂max. This correlation was observed in lower blood lactate accumulation and efficiency in higher fit trained distance runners at a specific running velocity among highly fit trained runners (Costill et al., 1973).

The best elite runners in the world have exhibited the best RE measurements (Lucia, Olivan, Bravo, Gonzalez-Freire, & Foster, 2008). Of these runners, Kenyan runners stand out, as Kenya is the dominating country within international competitions. Kenyan runners have been compared with Scandinavian runners of similar VO₂max levels (Saltin et al., 1995). Kenyan runners exhibited lower oxygen costs at various velocities or better running efficiency, compared to the Scandinavian runners. Research has exhibited the high importance of having a high RE (Weston, Mbambo, & Myburgh,
2000). Again, African distance runners were compared to Caucasian runners, and, even though the African runners displayed 13% lower VO$_2$ peaks, they exhibited greater running economies at 16.1 km/hr (Weston et al., 2000). Mean oxygen consumption values were 5% lower in African runners at this velocity. Furthermore, African runners showed greater HRs and %VO$_2$peak values at race pace without differences in plasma lactate values. This ability to maintain greater HR and VO$_2$ values at race pace is most likely linked to the greater RE values and supports the importance of measuring RE

**Training Methods**

For a single training session, each training method includes both an intensity and duration (Wenger & Bell, 1986). Training intensities have been debated as to which intensity elicits the greatest improvements in aerobic capacity and performance. Cross country coaches and athletes construct training programs that aim to gain the most benefit as efficiently as possible. When determining which training variables to manipulate in order to produce the greatest improvements in VO$_2$max, intensity and duration were seen to have the largest improvements on VO$_2$max (Davies & Knibbs, 1971). Training below 50% VO$_2$max did not show any improvements in maximum aerobic power for any participants (Davies & Knibbs, 1971). There is evidence supporting the importance of high intensity exercise in order to gain mitochondrial function in skeletal muscle for trained male athletes (Daussin et al., 2008). In this comparison study, trained athletes had significantly higher mitochondrial capacities in glutamate-malate, pyruvate, and succinate volumes. This indicates that those who partook in normal high intensity training displayed an increased ability to perform aerobic exercise.
There are various training methods that have emerged in order to improve the endurance performance variables. The three primary training methods include long slow distance (LSD), AT training, and interval training (IT). LSD is characterized as running for long periods at low intensities and has been validated as an effective training method for novice endurance athletes (Dolgener, Kolkhorst, & Whitsett, 1994). Alternatively, in higher trained runners, LSD training was not effective in improving VO$_2$max or LT compared to other training methods over an eight week period (Helgerud et al., 2007). The other training methods included LT training and IT (Helgerud et al., 2007). In this study LSD was characterized as 45 minutes of running at 70% HRmax. RE was significantly improved (p < 0.05) in the LSD group, but only IT training was able to improve VO$_2$max (p < 0.001), RE (p < 0.01), and the velocity at which LT was observed (vLT) (p < 0.01) (Helgerud et al., 2007).

Integrity seems to outweigh the other training variables in highly fit trained runners. High intensity training in athletes who train on a regular basis showed greater adaptations in skeletal muscle function than sedentary individuals (Daussin et al., 2008). Furthermore, in higher fit athletes with a VO$_2$max above 50 ml/kg/min, a minimum intensity of 50% VO$_2$max was needed to elicit improvements in aerobic capacity. Training at 90-100% VO$_2$max was seen to elicit the greatest improvements in fitness (Wegner & Bell, 1986). Therefore, intensity presents itself as a training variable that can be manipulated in order to have large impacts on the training adaptations.

Interval training is a unique training method used to bring about physiological changes. It is a widely used method for high intensity training because athletes can train
at speeds and intensities similar or above those expected in a competition. Significant improvements in Vmax have been seen in highly trained male endurance runners following 4 weeks of interval training for 1 Vmax session out of 6 training sessions per week (Billat et al., 1999). This change was accredited to a significant improvement in RE because VO2max values did not significantly increase, whereas the RE values improved from 50.6 (± 3.5) ml/kg/min to 47.5 (± 2.4) ml/kg/min after 4 weeks. Additionally, HR while running at 14 km/hr was significantly reduced (Billat et al., 1999).

Lastly, AT or LT training has exhibited better results beyond LSD training and similar benefits to those of seen with interval training for RE and LT but not for VO2max (Helgerud et al., 2007). In this study, LT was described as 85% HRmax. Previously mentioned research has shown that training at intensities above LT induced a significant change in VO2LT (48%) and VO2LT/VO2max (42%) compared to equal and below LT training groups (Henritze et al., 1985). These results strengthen the necessity for competitive runners to train at higher intensities in order to elicit the desirable physiological and performance benefits.

**Injury**

Although there are many benefits to improving one’s health, fitness, and performance levels from running, there are many adverse injuries associated with running. It is estimated that 79.3% of runners have experienced a running related injury within a 1 year span (van Mechelen, 1992; van Gent et al., 2007). A single race analysis surveyed 4,358 male runners in the 16 km (10 mile) Grand-Prix of Bern race (Marti, Vader, Minder, & Abelin, 1988). Of all race participants, 83.6% responded and 45.8%
had experienced a running related injury within one year prior to this race. Runners competing in the Rotterdam marathon were surveyed and displayed that 54.8% of race participants had incurred a running injury within 1 year of this race (van Middelkoop et al., 2008).

A running injury was defined as “an injury to muscles, joints, tendons, and/or bones of the lower extremities (hip, groin, thigh, knee, lower leg, ankle, foot, toe) that the participant attributed to running” (Macera, Pate, Powell, Jackson, Kendrick, & Craven, 1989). Authors have noted the most common running injuries in the lower extremity to the feet, calf, and the knee (van Middelkoop et al. 2008). Running injuries can further be divided into overuse and acute injuries (Matava, 2008). Overuse injuries are chronically developed, and acute injuries occur over a short period of time, such as a sprained ankle. Long distance runners can incur both types of injuries with a higher prevalence for overuse injuries, such as chronically incurring stress fractures, tendinitis, and patellar femoral pain, commonly known as runner’s knee, due to repetitive movements (van Middelkoop et al., 2008). Furthermore, overuse injuries are prevalent among competitive runners and are frequently a result of training errors that can lead to injury (Lysholm & Wiklander, 1987; Wilder & Sethi, 2004).

The training errors that can lead to injury among runners include increasing run training volume too quickly in a short period of time, improper footwear, excessive intensity sessions, and running for too long of a duration during one exercise session (O’Toole, 1992). Injuries can also be attributed to running technique issues and a history of running injuries (Wilder & Sethi, 2004). Although it appears that chronic inflammation
is lower in runners (King, Carek, Mainous, & Pearson, 2004), overuse running injuries still remain prevalent. It is common knowledge that at higher intensities greater forces will be exerted on the legs of a runner which can lead to injury. Specifically, eccentric loading of the legs has produced greater increases in muscle damage (Evans et al., 1986; Ide, Nunes, Brenzikofer, & Macedo, 2013). Ultimately, injuries of any kind can cause a reduction or cessation in run training (Marti et al., 1992). A reduction or cessation in training volume can physiologically, psychologically, and emotionally impact the training and performance levels for a runner.

Detraining

The physiological improvements of endurance training can fade after the discontinuation of training. This cessation of exercise has broad effects on the cardiovascular and other body systems. An extensive review of detraining and the adaptations that are associated with this condition has been established (Mujika & Padilla, 2000). In this review, it states that detraining is a term used to describe the principle of reversibility, which has been established as the loss of physiological adaptations that were gained through exercise training. Detraining is also often used to describe the physiological effects due to a reduced volume of training (Mujika & Padilla, 2000). Two detraining types were discussed: short and long term. The dividing line that separates short and long term detraining is 4 weeks duration.

Partial detraining consisted of no vigorous exercise and low levels of other activity. A decrease in VO_{2max} values (6%) was seen following 4 weeks of detraining in endurance trained athletes and was attributed to a decrease in blood volume (Coyle,
Hemmert, & Coggan, 1986). This decrease in blood volume was even greater in higher trained athletes (Coyle et al., 1984). A decrease was also seen in stroke volume after this period, which further explains the demonstrated decline in VO$_2$max (Coyle et al., 1984). An 8% decrease has also been observed in cardiac output following a 21-day period (Coyle et al., 1984).

Furthermore, a significant decrease in AT was seen after 6 and 9 weeks in cycle trained athletes (Ready & Quinney, 1982). This decrease could have been earlier in the detraining period, but testing was only conducted every 3 weeks. Of the greatest importance to note, running performance has also decreased following a period of detraining (Houmard et al., 1992). Motivated and competitive athletes seek to maintain or limit the amount of loss in physiological or performance parameters. This is most often done through cross-training methods.

**Cross-Training**

Training using a different modality apart from the athlete’s sport specific modality in order to improve in the athlete’s main sport is referred to as cross-training. An established training principle in the sport performance and exercise physiology community is the principle of specificity. The principle of specificity is a phenomenon that states the specific training stimuli will cause specific adaptations according to the sport-specific stress placed on the body. In many cases sport specific training is not possible for runners. Injured runners and their coaches have searched for the most effective alternative forms of exercise in order to maintain or prevent detrimental losses in fitness and run performance due to detraining. Cross-training is innately different than
the sport specific run training a runner would normally utilize. Nonetheless, there are currently many forms of cross-training that have been established in accordance with the principle of specificity including the ARC trainer (Turner, Williams, Williford, & Cordova, 2010), stair climber (Egana & Donne, 2004), elliptical (Dalleck, Kravitz, & Robergs, 2004; Joubert, Oden, & Estes, 2011; Mercer et al., 2001; Mier & Feito, 2006), deep water running (Bushman et al., 1997; Butts, Tucker, & Greening, 1991; Dowzer, Reilly, Cable, & Nevill, 1990; Eyestone, Fellingham, George, & Fisher, 1993; Svendenhag & Seger 1992; Wilber et al., 1996), antigravity treadmill (Patil et al., 2012), and the street strider (Becker, Porcari, Foster, Doberstein, & Anders, 2011). Other common forms of cross-training for runners include the cycle ergometer (Pizza et al., 1995; Porcari et al., 1998) and swimming (Foster et al. 1995).

Cycling is a popular cross-training modality for its ability to provide a high intensity but low impact workout (Porcari et al., 1998), although unable to elicit maximal cardiovascular responses similar to the treadmill (Mays, Boer, Mealey, Kim, & Goss, 2010). A study investigated the effects of cycling cross-training compared with run training on running performance factors (Pizza et al., 1994). These authors found that the VO2 used to determine RE was significantly higher, producing a worse RE, following 10-days of cycle ergometer training in trained runners (Pizza et al., 1995). However, there was no significant difference found in 5,000 m running performance.

An investigation compared elliptical and cycling cross-training on high school runners following a competitive season (Honea, 2012). Five weeks of cross-training with either modality produced significantly slower 3,000 m time trial times compared to a
control group that continued normal run training. Both VO$_2$max and LT were unchanged following training, indicating an importance of run specific training on performance (Honea, 2012). These two previous investigations indicate the difference between training duration and modality. Over a 10 day duration revealed no changes in performance (Pizza et al., 1995) whereas 5 weeks displayed significant decreases in running performance (Honea, 2012). Research suggests that longer term cycle cross-training is not effective in maintaining run performance.

Another popular form of cross-training is swimming. Swimming has been investigated as an effective cross-training method for runners and, although popular, was not seen to be an effective training method for eliciting VO$_2$max values similar to those elicited on a treadmill (Holmér, Lundin, & Eriksson, 1972). However, an increase in swimming VO$_2$max in college recreational trained male swimmers following 10 weeks of swim training was seen without a subsequent improvement in treadmill VO$_2$max (Magel et al., 1975). These results display the principle of specificity discussed earlier. A maximal swimming test in elite swimmers elicited a significantly lower VO$_2$ max, HR max, and VE max compared to a maximal running test on a treadmill (Holmér et al., 1974). It has been postulated that exercising in the water can differ physiologically due to the hydrostatic pressure effect of water, water temperature cooling effects, and familiarity with water exercise (Avellini, Shapiro, & Pandolf, 1983).

Swimming was utilized as a cross-training modality in an 8 week period in well-trained individuals (Foster et al., 1995). Participants were placed in either a run or swimming group. Additional training loads beyond normal training were administered for
8 weeks in each training group. Enhanced training significantly improved 3.2 km run performance times by 13.2 seconds and 26.4 seconds in the swimming and run groups, respectively (Foster et al., 1995). Performance improvements were significantly greater in the run group compared to the swimming group (Foster et al., 1995). The principle of specificity in well-trained individuals who trained primarily by running is evident in this study. A significant improvement in arm crank VO\textsubscript{2} peak was displayed indicating possible improvements in upper body mechanics that transferred to an individual’s RE. Nonetheless, enhanced sport specific run training was supported as a superior training method compared to swimming cross-training in trained runners (Foster et al., 1995; Magel et al., 1975).

The effects of different training modalities on lactate threshold were investigated. Pierce, Weltman, Seip, and Snead (1990) demonstrated this principle by finding that the run training group improved their treadmill and cycle VO\textsubscript{2} peak (11.9%) and VO\textsubscript{2} at LT (58.5%) following 10 weeks of assigned training. The cycle training group saw an increase (38.7%) in cycle VO\textsubscript{2} at LT but no improvement (1.6%) in treadmill VO\textsubscript{2} at LT (Pierce et al., 1990). Conversely, the run training group showed a less significant increase in cycle VO\textsubscript{2} peak (13.3%) and VO\textsubscript{2} at LT (20.3%). Although this study utilized previous sedentary individuals, it was still able to effectively demonstrate the specificity principle.

Stationary exercise machinery, such as the ARC trainer, stair climber, and elliptical trainer have been investigated and have been found to produce varying results. The ARC trainer has shown conflicting results in a study that compared the ARC trainer and treadmill maximal values (Turner et al., 2010). The maximal HR elicited by the ARC
trainer was significantly less than the treadmill value, but maximal VO\textsubscript{2} and time to maximal value were not significantly different (Turner et al., 2010). The results from a study comparing the stair climber and treadmill in moderately active females were in harmony with previous literature (Egana & Donne, 2003). This study demonstrated that stair climbing exercise can increase maximal measurements including VO\textsubscript{2} and VE over a 12-week training period. Although a cycle ergometer was used for maximal testing, this study still demonstrates the effectiveness of the stair climber. Other research has demonstrated benefits of stair climber use versus run training in nonrunner participants (Loy et al., 1993). VO\textsubscript{2max}, %VO\textsubscript{2max}, %HR\textsubscript{max} and time trial time were significantly improved following a 9-week training period for both the run and stair climber group (Loy et al., 1993). A major limitation for this study was the use of fit, non running specific participants who might have not been accustomed to consistent run training. No known studies have investigated the effectiveness of the stair climber on cross-training for runners, however, there are obvious differences between the dynamic running motion and stationary stair climbing motion.

Another generally accepted, low impact form of cross-training that is similar to running is the elliptical cross-trainer. The elliptical cross-trainer was invented in the early 1990s, and its popularity is evident as a 220\% increase in elliptical use was seen from 2000-2007 (Sporting’s Good). An elliptical is a common cross-training choice for its low impact, high intensity, running like exercise motion. Much research has shown an elliptical can produce similar VO\textsubscript{2max} values to a maximal treadmill test (Dalleck et al., 2004; Mays et al., 2010). An elliptical trainer elicited a maximal VO\textsubscript{2}, HR, and RER
during a graded exercise test performed on a Precor elliptical cross-trainer compared with a treadmill in recreationally trained, young to middle aged 29.5 years (± 7.1) individuals (Dalleck et al., 2004). Additionally, the time to fatigue was not significantly different between modalities.

$\text{VO}_{2\text{peak}}$ values did not differ between the elliptical and treadmill running (Mays et al., 2010). In agreement is an investigation which also found no significant difference between maximal values using the elliptical trainer and the treadmill in recreational active women (Porcari et al., 1998). Maximal $\text{VO}_2$ was significantly greater during treadmill running compared to the elliptical. Concurrently, this significantly lower $\text{VO}_2$ value was also seen at 75% and 90% heart rate reserve (HRR) in the elliptical group (Garlatz, Brilla, Knutzen, & Chalmers, 2008). Significantly greater RPE and blood lactate values were seen in the elliptical group at 90% HRR. These results suggest differences in physiological responses based on modality.

Not in accordance with previously mentioned research, the HR and RPE of the elliptical cross-trainer and ARC trainer were compared with the treadmill. The elliptical group displayed significantly greater HR values at submaximal intensities of 55%, 65% and 75% (Turner et al., 2010). Greater maximal HR values of 188.9 bpm (± 7.8) were displayed in the treadmill group. The ARC trainer had similar HRmax and $\text{VO}_{2\text{max}}$ values of 185.0 bpm (± 8.0) and 51.2 ml/kg/min (± 12.1), respectively, when compared to the elliptical, which had HRmax and $\text{VO}_{2\text{max}}$ values of 184.2 bpm (± 8.4) 50.2 ml/kg/min (± 11.1), respectively. These data display the closeness but differences
between all three modalities: the ARC trainer, elliptical trainer, and treadmill running found in this study (Turner et al., 2010).

The VO$_2$max of recently trained runners was tested using the elliptical cross-trainer (Joubert et al., 2011). Untrained male and female participants ($n = 20$) trained by running over a 4 week period including four runs per week at 80% HRmax for 30 minutes. Following this first phase, participants were prescribed either a run, elliptical, or no training modality for an additional 3 weeks at the same training intensity, duration, and frequency. A VO$_2$max test was performed pre, post 4 weeks of run training, and post final 3 weeks of training. Following the second phase of 3 weeks, no significant changes in predicted VO$_2$max values were observed for any of the three groups (Joubert et al., 2011). This suggests that the elliptical is a valid mode for maintaining physiological variables for a 3 week period absent from running in recently trained runners. This scenario is common for new runners beginning training.

Even more sport specific modes of cross-training have been developed. An alternative to full body land running is the use of an antigravity treadmill (Patil, 2012). Antigravity treadmills are most often used during rehabilitation periods when full body weight cannot be sustained on over ground running. Antigravity treadmills can unweight an individual up to 100% of one’s body weight. Studies have shown a reduction in ground reaction forces during reduced body-weight exercise (Cutuk et al., 2006; Grabowski & Kram, 2008). Differences in RPE were not seen at running speeds eliciting a VO$_2$ of 25 ml/kg/min with decreases in ground reaction forces (Hoffman & Donaghe, 2010). However, antigravity running at 40% body-weight support has been found to
significantly change the running gait of a runner, including a longer stride, decreased cadence, and restriction of upper body torso rotation (Millslagle, Levy, & Matack, 2006). These changes indicate the decreased body-weight load while running, which could impact the training effects following an antigravity treadmill running program.

In a case study of an elite female runner who was returning from a pelvic stress fracture after 8 weeks of 95% body-weighted supported treadmill running, she was able to qualify for the NCAA 10,000 m championships (Tenforde, Watanabe, Moreno, & Fredericson, 2012). This case study suggests that reduced body-weight running is effective in enabling a runner to run train during periods of rehabilitation, although training also included deep water running (DWR) and other rehabilitation training. Regardless of the effectiveness of the antigravity treadmill it is primarily limited to elite and professional athletes due to its cost. The cost of an antigravity treadmill begins at $30,000 or several hundred dollars for a monthly gym membership for use of their antigravity treadmill. Both options pose substantial cost limitations for the majority of runners.

Another alternative form of cross-training that aims to be very sport specific for runners is DWR. While immersed in water up to the neck or upper chest level, form used during DWR aims to produce a similar land running motion. The allure of DWR is its ability to emulate the land running motion in the water with no impact forces occurring or restrictive equipment. Many studies have compared the physiological responses during DWR and land running and found lower maximal VO$_2$ and HR values in DWR in trained runners (Butts et al., 1991; Chu, Rhodes, Taunton, & Martin, 2002; Dowzer et al., 1990;
Frangolias & Rhodes, 1995; Svedenhag & Seger, 1992). In 24 trained participants (12 men, 12 women), two groups performed both a treadmill and DWR VO\(_2\) max test. DWR displayed significantly lower maximum VE, VO\(_2\), and HR values (Butts et al., 1991). Women and men displayed 16% and 10% lower VO\(_2\) max values, respectively, with no significant difference between genders. These results suggest a limitation in DWR as a cross-training technique for high intensity running. However, Butts et al. (1991), advocate DWR as a valid cross-training technique, but do mention exercise intensity prescription will differ from land running.

Other research by Svendenhag and Seger (1992) also displayed significantly lower maximal HR and VO\(_2\) values during graded exercise tests in DWR in trained male distance runners. These same physiological responses were shown at submaximal intensities as well (Svendenhag & Seger, 1992). On average, at any given VO\(_2\), DWR elicited a 10.9 bpm (± 2.1) lower HR than land running. Additionally in this study, the leg RPE values were significantly greater at 3.5 L/min while running on land 14.6 (± 0.6) v. 12.6 (± 0.7), and blood lactate values, 30 seconds post exhaustion, were greater in the water, 12.4 (± 1.3) v. 10.0 (± 0.6). This was also seen in an acute bout of sprinting in water compared to land sprinting (Cook, Scarneo, & McAvoy, 2013). A vest was worn during DWR in both studies. These authors suggest that higher blood lactate values post exercise with lower maximal VO\(_2\) values might be due to an increased reliance on anaerobic energy pathways. One suggestion for why there might be increased anaerobic energy pathways used is the unfamiliarity with DWR. This might be explained by the fact that both studies only provided limited instruction and familiarization sessions for their
participants before they were tested. Neither study used participants who had substantial DWR experience to the point that DWR was their primary form of training.

Similarly, water running can be performed in shallow water where the feet are in contact with the ground in a similar way to land running. Shallow water running (SWR) in trained male runners has shown similar physiological responses when compared with treadmill running (TM) (Dowzer et al., 1990). Significant differences were observed when comparing maximal values for both shallow and deep water levels as compared to treadmill running (Dowzer et al., 1990). Significant differences were also displayed for SWR compared with DWR. Significantly greater maximal VO$_2$, VE, and HR values were elicited in SWR compared to DWR. A large percentage of treadmill VO$_2$ max (83.7%) compared to DWR (75.3%) indicating a possible effect of these shoes and other differences between water levels. Additional differences should be looked at when considering either water running method as a valid form of cross-training. All conditions were similar to previous studies, however, in the SWR maximal test, pool shoes were worn. This may have increased muscle recruitment due to the increase in distal weight on the feet or increased drag (Divert et al., 2008). No shoe weight or drag effects were reported. Additionally, the muscle action of the calf muscles during the push off phase could also contribute to increased energy demand.

Further physiological and biomechanical measures beyond VO$_2$ max have been studied in DWR for elite endurance runners, such as respiratory exchange ratio (RER), ventilatory threshold (VT), RPE, and blood lactate (Frangolias & Rhodes, 1995). Female and male participants had an average VO$_2$ max of 53.7 (± 4.2) and 63.4 (± 4.2),
respectively. Significantly lower maximal VO$_2$, RER, and HR measurements were taken at VT and maximal exercise intensities for DWR compared to land based treadmill running. However, RPE and blood lactate values were not significantly different, indicating that participants gave a maximal effort. Frangolias and Rhodes (1995) speculate that the greater blood lactate and lower maximal VO$_2$ values indicate a difference in DWR versus land running which had previously been postulated (Svendenhag & Seger, 1992). Masumoto, Horsch, Agnelli, McClellan, and Mercer (2013) found significant lower gastrocnemius muscle activity (41%) in DWR compared to land running on a treadmill. Activity in the rectus femoris, biceps femoris, and tibialis anterior muscles did not exhibit any significant differences. These differences indicate a muscle activation difference between modalities. These differences might also depend on the specific DWR technique, which was not reported (Killgore, Wilcox, Caster, & Wood, 2006). Further differences in stride frequency was lower in the water conditions compared to land running conditions (Frangolias & Rhodes, 1995) suggesting a change in running biomechanics from land to water running.

Of greater importance for the distance runner is the ability to chronically cross-train using DWR. This has been investigated in several studies (Bushman et al., 1997; Eyestone et al., 1993; Wilber et al., 1996). Bushman et al. (1997) demonstrated the ability that DWR can maintain running performance in a 5,000 m time trial, maximal VO$_2$, and running velocity at LT following 4 weeks of DWR in competitive well-trained runners. This study did concur with other previous evidence that DWR was sufficient to maintain running performance in recreational active runners over 6 weeks (Eyestone et al., 1993).
In this study, there was a statistical decrease in VO$_2$max for all participants in any of the three groups: DWR, land running, and cycling. However, it was determined that there was no physiological difference between DWR and other training modalities from pre to post measurements (Eyestone et al., 1993). Wilber et al. (1996) further improved upon both of these studies by DWR training only for 6 weeks, including high intensity (> 90% VO$_2$max) training. No differences were seen between groups for VO$_2$max, VT, RE, or blood lactate. Thus, DWR might provide an appropriate training stimulus in order to maintain physiological and performance variables despite the consistent inability to obtain VO$_2$max values compared to land running.

A unique study demonstrated the effects of replacing 30% of land run training with DWR for 8 weeks compared to a group that continued to perform all training on land (Peyré-Tartaruga et al., 2009). There were no significant differences in VO$_2$peak, VT, RE, or kinematics between the groups following this training program. This study was unique by replacing a percentage of land running training volume with DWR over an 8-week period. Kinematic differences between DWR and land running have previously been suggested due to the inability to contact the ground and changes in blood lactate values with lower maximal VO$_2$ values. Overall, DWR presents itself as a viable cross-training option for runners in order to maintain their fitness levels and performance. In order to exercise in the water there are many limitations, including: availability of a pool, cost of admittance, ability to obtain high intensity training, and generally low levels of enjoyment.
A distinct exercise machine exists to reproduce the elliptical experience outdoors (Becker et al., 2011). The StreetStrider (SS), invented by David Kraus from the University of Alabama in 2005, offers the elliptical experience outdoors on a three wheeled exercise machine. Becker et al. (2011) tested the SS compared to a stationary elliptical. Following a maximal VO$_2$ test on an elliptical (Precor® EFX 576i), participants performed 30 minutes of exercise at a self-chosen pace for each modality while HR, VO$_2$ and EE were measured. The SS had significantly greater values for HR, EE and VO$_2$ percentages. At self-selected intensities, the SS garnered 85% HRmax and 71% VO$_2$max, which was 13% greater than the stationary elliptical (Becker at al. 2011).

Although these results are beneficial for the general population, the SS is limited as a viable option for highly fit and competitive runners. High fit runners aim to emulate high intensity running workouts whereas the SS was designed for the lay person looking to receive a high caloric expenditure, low effort workout. Another limitation of the SS is the difficulty for steering. Riders must use the entire body to lean in the direction they wish to turn. At high speeds safety issues are presented. These issues may limit the duration a rider can ride before slowing to redirect their path.

Since 2009, a new piece of exercise equipment has been on the market called the ElliptiGO. The ElliptiGO was designed by two runners who saw a need for a low impact cross-training machine that better emulated running compared to other forms of cross-training and could be ridden outdoors (Outdoor Elliptical Bikes-ElliptiGO, 2014). There is limited research on the ElliptiGO, as only one clinical report was found from the Exercise and Physical Activity Resource Center (EPARC) detailing the ElliptiGO.
Although this report has not been published or peer reviewed, it will be discussed. This study compared the acute physiological responses of riding an ElliptiGO 8S to an 18 speed road bicycle and running (EPARC, 2011). Participants (n = 6) performed four 6-minute bouts of exercise on each modality at predetermined speeds. Speeds for the ElliptiGO and cycle were between 11 and 18.5 mph at a cadence of 70-90 rpm with running speeds between 6 and 8.6 mph. Testing took place on the San Diego Velodrome, asphalt surface, on three separate days within a 4-day period. Results showed a significant (33%) greater EE while riding the ElliptiGO compared to the cycle at any given speed (EPARC, 2011). Participant variability ranged from ± 17% to ± 8% for the lowest and highest speeds, respectively. The EE while running at 7.5 mph were similar to the EE of riding the ElliptiGO at 16 mph. The EE at 8.6 mph running was similar to 18.5 mph for the ElliptiGO (EPARC, 2011). Similar HR and VO\textsubscript{2} values measured between these intensities as well, although no statistics were calculated. HRs using the fourth intensity for the ElliptiGO was 169 bpm (± 11.0) and was 169 bpm (± 7.0) for running. Exercise modes were similar and displayed evidence of the ElliptiGO’s ability to elicit high intensity exercise. RPE values were similar and averaged 9.25 (± 0.80) and 9.00 (± 0.71) for the ElliptiGO and run group, respectively. Thus, the ElliptiGO might offer a training stimulus similar to running and 33% greater than cycling.

However, there are proposed issues with this study. Testing was conducted using a small sample size (n = 6) with large apparent intra subject variability, which was a proposed cause of high calculated standard deviations. Subjects deviated in fitness levels, body sizes, and experience for each exercise modality. $P$-values that are used to
determine significance were not reported in this study. Furthermore, the amount of missing data was high due to either equipment malfunctioning, or the participant’s inability to exercise at the prescribed intensity (EPARC, 2011). Two participants did not record any running data, and 5 out of the 6 participants were either unable to complete all exercise intensities or the data were not reported. This lack of data could have resulted from the study’s methodology, lack of participant fitness levels, or low experience with testing equipment. An allotted 10 minutes was given in between exercise modes and only 1-2 minutes of active recovery in between bouts of exercise. Total exercise time equated to 72 minutes and intensities were moderate to high intensities based on average metabolic equivalent (MET) values (ACSM, 2010, p. 5). Some participants were unable to perform faster speeds due to fatigue indicating major limitations.

Additionally, the testing order was not randomized. It was consistent for all but one participant (EPARC, 2011). It was noted that this design was chosen to hold the wind constant between exercise bouts since testing was held outdoors. This poses another limitation as wind information was not reported. An indoor facility or use of a stationary trainer might have improved consistency between exercise modes. Furthermore, the circular shape of the Velodrome might have influenced the VO₂ values as participants might have had to increase or decrease intensity in order to maintain specified velocity on the curvature of the track.

The ElliptiGO was designed as an alternative exercise machine for running that closely emulates the running motion. The ElliptiGO motion is similar to the elliptical motion which allows for the comparison of the elliptical to the EllpitiGO. There are
however three main differences between exercise machines. First, the ElliptiGO allows for a variable and longer stride length ranging from 16-25 inches (41-64 cm) compared to traditional elliptical machines with stride lengths ranging from 16-21 inches (41-53 cm) and often are preset to a particular length. Secondly, the ElliptiGO does not have a fly wheel which lightens the total weight and removes the momentum effects that an elliptical produces. Lastly, a running specific recovery leg swing was manufactured. This difference positions the ankle into a more plantar flexed position with the toe pointing towards the ground. Additionally, the ElliptiGO’s handlebar height can be adjusted to the height of the rider. This handlebar adjustment improves upon a set handlebar height seen with elliptical trainer machines that have been related to various back issues (Moreside & McGill, 2012). The uniqueness and unfamiliarity with the ElliptiGO’s training effects garners reason for this current study. The purpose of this study was to compare the physiological and subjective responses to a 4-week exercise training program using an ElliptiGO bicycle compared to a matched run training program.
Chapter 3: Methods

Participants

The Ohio University Institutional Review Board (IRB) reviewed and approved this research study. Twelve (n = 12) men (n = 6) and women (n = 6) ages 18-35 from Ohio University and the Athens, OH area were then recruited through flyers, emails, and verbal announcements. All potential participants voluntarily signed the written informed consent form during the consent process. Participants were healthy, trained and highly fit runners with an average of 9.25 years (± 4.73) running experience. Participants were nonsmokers, drug free and had no diseases or injuries that limited their ability to perform vigorous exercise. Participants must have had at least 1 year of running experience and also have been consistently run training for at least 2 months at a frequency of 3 days with one hard intensity session each week. Participants were excluded if they had presented any orthopedic injuries in the 3 months before beginning the study that prohibited them from running for more than 6 consecutive weeks during that time frame. Participants were not required to have previous elliptical, ElliptiGO or other cross-training experience to be included into this study.

Exclusionary conditions included heart disease, pulmonary, metabolic or other conditions that could influence the inflammation response including Crohn’s disease, severe arthritis, cancer or a previous heart attack. Participants that were pregnant were excluded from this study. Blood pressure equal to or greater than 140/90 mmHg was considered high blood pressure (ACSM, 2010, p. 47) and warranted exclusion from this study. Those on blood pressure medications were also excluded from this study. A
participants’ BMI and body fat percentage (BF%) were used as methods for determining a healthy participant. Participants were included if their BMI values were within the normal or overweight ranges of 18.5-29.9 kg/m² (ACSM, 2010, p. 63). Participants were required to have a BF% between 3.0-23.1% for men between 18-29 years old and between 7.0-24.9% for men between 30-35 years old. Women ranged between 9.8-27.1% and 11.0-29.1% for ages 18-29 and 30-35, respectively. These ranges represent the 50th to 99th percentile for these age groups (ACSM, 2010, pp. 71-72). Participants were included if their VO₂max values were equal to or greater than the 90th percentile values for their age group (ACSM, 2010, pp. 84-87).

**Procedures**

Following IRB approval, recruitment of participants, the consent process, and the preliminary screening process, qualified participants then ran a 5,000 m time trial on a standardized 400 m outdoor track. The preliminary testing session and time trial constituted testing session one for those participants who qualified and continued participating. Following the time trial, participants were randomly assigned into a training period of either ElliptiGO training (ET) or run training (RT) of matched frequency, duration, and intensity.

Random assignment was done through an online research randomizer (Research Randomizer, 2014) used by the Social Psychology Network. Each 4-week training period included 20 prescribed exercise sessions. Prescribed intensity zones were easy (HR < HR at AT), medium (HR range = HR at AT to HR at RCP) and hard (HR > HR above RCP) as determined by the VO₂max test. Percentages of training in these zones were 80%, 15%
and 5% for easy, medium and hard, respectively. These ranges were representative of an endurance athlete’s training (Esteve-Lanao, San Juan, Earnest, Foster, & Lucia, 2001).

Participants that were assigned to the ET period underwent a familiarization period to ensure each participant could safely and properly ride the ElliptiGO. Participants were instructed to wear a helmet at all times while riding the ElliptiGO, to not cease leg movement at any time, and to verbally notify bystanders of their riding path. At the completion of the 4-week training period, participants then returned to the lab for identical testing as in testing session one. Next, participants began a second training period of matched training frequency, duration and intensity to the first training period in a crossover design. After completing the second training period via the other training modality participants then concluded their participation by performing a third testing session, identical to the previous two. A diagram of the study’s methods can be found in Figure 1 (see Appendix I).

**Preliminary Screening**

After approval by the IRB, participants then had the opportunity to ask questions. After signing a written, informed consent form, preliminary screening occurred including completion of the HHQ and RHQ. Measurements of resting BP, HR, height, and weight were collected to determine a participant’s health and run training status. The determination of aerobic fitness via VO₂max test was then performed. If participants met the aforementioned inclusion criteria they were qualified to participate in this study.
Health Status

The HHQ was filled out indicating any contraindications for vigorous exercise or participation in this study. Resting BP and HR measurements were taken following a period of five minutes in the seated position. A measurement of BP was taken using a sphygmomanometer and BP cuff appropriate to the size of each participant’s upper arm. Those with BP measurements equal to or greater than 140/90 mmHg were excluded from this study (ACSM, 2010, p. 47). A HR monitor (Polar, Lake Success, NY) was used to measure resting HR. Researchers then collected anthropometric information needed to perform a BMI calculation, including height and weight. Height was measured as centimeters (cm) using a stadiometer. Participants were instructed to remove their shoes, stand with their back to the height ruler, look straight forward and breathe in deeply, then exhale. Heights were then converted to meters (m) for calculation of BMI. Weight was measured as kilograms (kg) with an electronic weight scale. BMI was calculated by dividing body mass (kg) by meters of height (kg/m²). Participants that met the aforementioned health status inclusionary criteria were further assessed for body composition.

Body composition was assessed by measuring BF% using Lange skin fold calipers (Ann Arbor, MI) (ACSM, 2010, pp. 66-67; Roche, 1996). Calibration of skin fold calipers was performed prior to testing. This procedure included pinching the skin and measuring either a vertical, horizontal, or diagonal fold 1-2 cm from the thumb and the finger forming the pinch, at seven different sites including the: chest, triceps, subscapular, abdominals, midaxillary, thigh, and suprailiac. These sites were measured
twice on the right side of the body in a rotating order. A third measurement was taken if the first two measurements differed by more than 2 mm. The two closest measurements were averaged and used for the calculation of body density with the following equations:

\[
\text{Body density (men)} = 1.112 - 0.00043499 \times (\text{sum of skin folds}) + 0.00000055 \times (\text{sum of skin folds})^2 - 0.00028826 \times \text{(age)}
\]

\[
\text{Body density (women)} = 1.097 - 0.00046971 \times (\text{sum of skin folds}) + 0.00000056 \times (\text{sum of skin folds})^2 - 0.00012828 \times \text{(age)}
\]

Body density was then used to calculate the percentage of body fat:

\[
\text{Body fat\% (men)} = \frac{495}{\text{body density}} - 450
\]

\[
\text{Body fat\% (women)} = \frac{495}{\text{body density}} - 450
\]

**Running History**

Each volunteer filled out a RHQ that collected information on the participant’s previous running experience. This questionnaire was given following completion of the HHQ. The RHQ allowed researchers to determine trained runners from non-trained. Inclusionary criteria included participating in consistent endurance run training at a frequency of at least 3 days per week for at least 1 year prior to the beginning of this study. Consistent training could not have included extended breaks, more than 6 consecutive weeks, from running in the last 3 months. For a given exercise bout, the total run duration must on average have exceeded 20 minutes. Participants averaged 57.5 minutes (± 24.45) in duration for each exercise bout prior to the start of this study. Personal records from the mile to the marathon were also recorded.
The run training program must have had included at least 1 day per week of high intensity running (60-80% VO\(_2\max\)). High intensity is representative of VO\(_2\) percentages at the LT or above in trained athletes (Davis et al., 1979). If the VO\(_2\) percentages were unknown, high intensity was considered as at least a 13-15 value rating from RPE scale for total body, which has been comparable to intensities at LT (Weltman, 1995). The talk test was also used to determine high intensity running. The VT was seen as the point when speech first becomes difficult during exercise (Persinger, Foster, Gibson, Fater, & Porcari, 2004). Prior to the start of their participation in the ElliptiGO study, participants averaged 4.46 (± 1.14) run sessions, 2.17 (± 1.44) hard intensity run sessions, and 37.74 (± 18.64) kilometers total per week.

**Maximal Oxygen Consumption Testing**

Following qualifying as healthy and trained runners, participants were assessed for high fit status by a relative VO\(_2\max\) measurement from a graded exercise treadmill test (GXT). Men were required to have a relative VO\(_2\max\) measurement of at least 54 ml/kg/min for ages 18-29 and a measurement of 52 ml/kg/min for ages 30-35. A relative VO\(_2\max\) measurement of at least 47 ml/kg/min or 45 ml/kg/min for women ages 18-29 and 30-35, respectively, was required to participate in this study. These values represent the 90\(^{th}\) percentile for these age ranges (ACSM, 2010, pp. 84-87). Measurements from GXTs allowed for the appropriate exercise prescriptions for each participant.

Determination of AT and RE measurements were performed following GXTs.

A motorized treadmill (TMX-425, Full Vision Inc., Newton, KS) was used for the GXTs. VO\(_2\max\) values were obtained and recorded during GXTs via a breathing
apparatus, which included headgear and plastic tubing connected to a calibrated metabolic cart (Truemax 2400 Metabolic Measurement System, ParvoMedics, Sandy, UT). Hans Rudolph one-way valves (Kansas City, MO) allowed for expired gases to be collected and transported to the mixing chamber of the metabolic cart. Fractions of oxygen and carbon dioxide gases were then analyzed breath by breath and the averages were displayed on the computer. The physiological measurements of ventilated oxygen consumption (VO$_2$), ventilated carbon dioxide (VCO$_2$), fraction of expired oxygen (FEO$_2$), fraction of expired carbon dioxide (FECO$_2$), respiratory exchange ratio (RER), ventilation (VE) and respiratory rate (RR) were collected from this analysis.

Participants were instructed to dress in athletic clothes and appropriate running shoe wear. Alcohol consumption, caffeine and vigorous exercise were avoided for at least 24 hours prior to the test. Energy drinks were not consumed prior to an exercise session due to proposed benefits in endurance performance (Alford & Wescott, 2000). Participants were given detailed instructions on their GXT procedures before the start of the test so that participants could ask questions. Each participant was fitted with a HR monitor (Polar, Lake Success, NY), mouthpiece, head gear and nose plug. Participants performed a warm up for 5 minutes before beginning the test. Equal verbal encouragement was given throughout the test.

An individualized, gender specific, GXT protocol was determined by researchers to ensure workloads will elicit a maximal effort within 8-15 minutes for each participant. This test began with a standing stage on the treadmill to collect baseline gas exchange values. Then the subsequent stages began at submaximal workloads and gradually
increased in speed every stage until the latter stages at which point the incline of the
treadmill was increased (Mooses et al., 2013; Saunders, Pyne, Telford, & Hawley, 2004).
This protocol was chosen in order to measure running economy during the GXT. Heart
rates were measured every 30 seconds during the GXT. The test continued until the point
of volitional exhaustion. At this time the participant straddled the stationary belt of the
treadmill. The GXT test was also stopped if the researcher deemed it unsafe or no longer
necessary to continue as suggested by the ACSM’s Guidelines for Exercise Testing and
Prescription (2010).

Participants were placed in a chair after removing plastic tubing and headgear. A
measurement of RPE was taken immediately following the GXT for the whole, upper and
lower body. Blood lactate measurements were taken 5 minutes after completion of GXT.
Finger prick blood samples were analyzed for lactate concentration by a Lactate Plus
analyzer (Lactate Plus, Nova Biomedical Corporation, Waltham, MA). Researchers
wiped the participant’s finger with an alcohol swab and let dry. Then a sterile, single-use
lancet was used to prick the end of the participant’s finger. After the first droplet of blood
was wiped away with a gauze pad, a second droplet of blood was used to measure blood
lactate levels with a handheld blood lactate analyzer. Following the measurement, an
appropriate sterile dressing and first aid materials were used as needed to control the
bleeding. Medical gloves were worn throughout the blood procedures.

Participants did an active walking or running cool down after blood lactate
samples were taken and recorded (Gass, Rogers, & Mitchell, 1981). Following the GXT
participants were monitored in order to ensure their safety. A valid VO_{2\text{max}} test occurred
when three out of the following five criteria were met: a plateau in VO\textsubscript{2} or increase less than or equal to 0.15 L/min with an increase in intensity, a RER > 1.1 or greater, a HRmax within 10 bpm of predicted HRmax, a blood lactate concentration ≥ 8 mmol/L, and an RPE of 18 or greater (Howley et al., 1995).

**Anaerobic Threshold**

AT otherwise referred to as VT, was found following the GXT via the pattern recognition AT detection method. This method was accomplished by confirming several identifiers. First, the workload or time point when the FEO\textsubscript{2} increased following a plateau period. Secondly, the FEO\textsubscript{2} increase was aligned with the workload when the ratio of VE/VO\textsubscript{2} increased without a subsequent increase in VE/VCO\textsubscript{2} (Caiozzo et al., 1982). A drastic increase in VE was also used to confirm that this workload was a true AT. AT was determined by one experienced researcher and confirmed by another blinded experienced researcher.

**Running Economy**

A participant’s RE, or milliliters oxygen used per kilogram of body weight for one kilometer (ml/kg/km) at a given running velocity, was measured during the VO\textsubscript{2max} treadmill test. The RE was measured during two stages of 3 minutes in duration during the GXT. These stages were standardized for all participants at 6 mph and 7 mph. To account for wind resistance, an incline of 1% was set for both velocities when RE was measured (Jones & Doust, 1996). Relative VO\textsubscript{2} values for each velocity were averaged over the final minute once a steady state VO\textsubscript{2} had been reached. A steady state was defined as an absolute VO\textsubscript{2} value that did not fluctuate more than 0.15 L/min.
Prevention Procedures

Participants were also monitored for common injury or illness. In the case that a participant incurred an injury or illness that prevented them from completing at least 75% of the training program they were not permitted to continue training in this study. At this time they were referred to an appropriate medical center or athletic trainer. Over the duration of this study, there were three incidences when this occurred. One incidence included a participant voluntarily releasing themselves from the study due to knee pain while running. The second participant was released from the study due to shin and ankle pain that occurred during testing session two following ElliptiGO training. The third participant became ill during the final week of training before testing session three and was released from the study.

Exercise Training

Participants either were given all required exercise training materials including an ElliptiGO, HR and a global positioning system (GPS) watch (Garmin, Olathe, KS) and charger, an exercise training schedule, and training notebook with subjective measurement materials. Both groups were equipped and familiarized with GPS monitoring equipment. The monitoring systems measured the following data: average and maximum HR, total distance, average speed and elevation. Researchers only allowed participants to train on the Hockhocking Adena Bikeway, an outdoor track, or flat sidewalk for either training period. These locations ensured a safe, traffic free and flat training area. When weather conditions did not safely permit outdoor exercise, a stationary trainer (CycleOps, Madison, WI) was used for ElliptiGO riding and a treadmill
or indoor track was used for running. The ElliptiGO stationary trainer allowed riders a similar riding experience indoors. When needed, the ElliptiGO bicycles were serviced by a professional bicycle mechanic in order to guarantee the safety of participants and integrity of the ElliptiGO equipment. Replacement of rear ElliptiGO tires was performed twice over the duration of the study. Tire inflation was held constant at 60 psi.

Participants were told the importance of properly handling the equipment as well as returning all lent equipment when requested by researchers.

**Subjective Measures**

Following each exercise session, participants recorded RPE values (Borg & Noble, 1974). An RPE value from 6-20 was asked of each participant for the following areas: lower, upper and whole body (Green, Crews, Pritchett, Mathfield, & Hall, 2004). Participants were instructed to decide this RPE value during the exercise bout and to use the highest rating that was decided upon. The muscle soreness scale used a Likert scale that included rating specific muscle groups of the body for feelings of delayed onset of muscle soreness (DOMS) (Smith et al. 1993; Thompson, Nicholas, & Williams, 1999). Thirty muscle groups were rated and the median rating was used for analysis for whole, upper and lower body measurements. Muscle soreness values aided in the indication that muscle damage had occurred. The Physical Activity Enjoyment Scale (PACES) (Kendzierski & DeCarlo, 1991) was assessed following the longest exercise session each week. This 18-item scale measured enjoyment by asking questions with a ranking scale of 1-7 in a counterbalanced manner. This survey was given at the time directly following the long exercise session at the conclusion of each week. These measurements were taken
each week and averaged over the 4-week training period. Higher scores indicated a higher level of enjoyment. Participants were encouraged to record any other information such as weather conditions, the time of day, tiredness, other stressors, feelings, physical pains or discomforts in their training notebooks.

**Controls**

Recovery methods were controlled in order to limit differences in recovery methods, which could have affected training adaptations independently. Participants were not allowed to use the therapeutic cold water immersion treatment, commonly known as ice bathing, anytime during this study to avoid enhanced muscle recovery following endurance training (Versey, Halson, & Dawson, 2012). Performance enhancing compression garments of any kind were not worn (Kemmler et al., 2009). Running clothing and a bicycle helmet were worn while riding the ElliptiGO. Closed-toe shoes were worn as footwear for all participants. Participants were asked to continue their normal diets for the duration of this study. No foods or fluids were provided to participants other than water. Caffeine was to be avoided within four hours of an exercise session.

**Statistical Design and Analysis**

Predictive Analysis Software (PASW Inc., Chicago, IL) was used to analyze and report means and standard deviations for each variable. A randomized crossover design was chosen for this study. A 2 x 3 factorial repeated measures analysis of variance (2 x 3 RM-ANOVA) was used to determine if an order effect was present by comparing relative AT at 0, 4, and 8 week time points, regardless of training modality. A RM-ANOVA
(within-ANOVA) test was used to compare VO$_2$max, AT, RCP, RE and 5,000 m time trial times across the three testing time points: initial, post- ElliptiGO (PE) and post- run (PR). The significance level was set at alpha $\alpha \leq 0.05$. A Fisher’s least significance difference (LSD) post hoc test was used to further analyze the significance between parametric variables (VO$_2$max, AT, RCP, RE and 5,000 m times). For nonparametric (ordinal) variables (RPE, soreness and enjoyment), a Friedman’s test was used for the three testing time points. A Wilcoxon signed rank test was utilized to compare these nonparametric (ordinal) variables between training periods. Finally, a 2 x 4 factorial RM ANOVA was used to compare training details, such as, exercise session frequency, duration, intensity and total time, for each training group.
Chapter 4: Results

This study aimed to compare physiological, performance, and subjective variables between ElliptiGO exercise and running in highly fit, trained runners over a 4-week training period. A 2 (training mode) x 3 (time) mixed factor ANOVA using relative AT was performed to assess if an order effect was present. There was no significant interaction ($p = 0.458$) and no significant difference between those who completed the run training first (RTF) and those who completed the ElliptiGO training first (ETF) ($p = 0.435$). There was a significant difference over time with a post hoc showing a difference between the initial test and following 4 weeks of training ($p = 0.025$) as well as following 8 weeks ($p = 0.034$) of training regardless of training modality.

A RM ANOVA showed that there were no significant differences ($p \leq 0.05$) among the initial, PE, and PR testing time points for age, height, weight, body fat, BMI, resting HR or BP. Table 1 displays the descriptive variables at the initial time point for all participants.
Table 1

Descriptive Information About Participants (mean ± SD)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>22.83 ± 3.33</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169.29 ± 9.98</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>62.33 ± 12.28</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>21.54 ± 2.29</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>10.68 ± 4.79</td>
</tr>
<tr>
<td>$\text{VO}_{2}\text{max}$ (ml/kg/min)</td>
<td>57.92 ± 9.68</td>
</tr>
<tr>
<td>Running experience (y)</td>
<td>9.25 ± 4.73</td>
</tr>
</tbody>
</table>

Matched exercise training periods were confirmed by reporting total exercise time, frequency, distance, and intensity. These variables were compared between each exercise training period. There were four different types of exercise sessions: easy, medium, hard, and long exercise sessions. All sessions were prescribed once per week except the easy session which was prescribed twice each week. The average total time per session for the entire training period was 41 minutes and 3 seconds for ET and 41 minutes and 33 seconds per session for RT. These times were determined to not be significantly different ($p = 0.658$) as told by a paired $t$-test. Total time for any single type of exercise session was not significantly different ($p = 0.135$) between ET and RT. On average the ET and RT training periods reported frequencies of 19.92 ($± 1.31$) and 19.50 ($± 1.00$) total sessions, respectively. These values were not significantly different.
between training periods ($p=0.210$). Average total distance was 14.32 km ($\pm 1.88$) for the ET and 7.72 km ($\pm 1.22$) for RT, which was significantly different ($p < 0.001$) between training periods.

A 2 x 4 mixed factor RM ANOVA using training groups and easy, medium, hard and long intensity sessions was conducted to compare actual average HRs between training groups, to determine differences in intensity. Actual average intensities did display a significant interaction ($p < 0.001$) between ET and RT groups and significant main effect ($p < 0.001$) among exercise intensities. Paired $t$-tests were used to break down the interaction in order to compare average HR intensities between ET and RT. A Bonferroni correction factor of $p \leq 0.0125$ was calculated for paired $t$-test comparisons between ET and RT groups for the four exercise intensities. It was determined that the average actual HRs for the medium ($p = 0.036$) and hard ($p = 0.017$) intensity sessions were not significantly different between training periods. Actual averages were significantly different for easy ($p = 0.003$) and long ($p = 0.001$) exercise sessions.

A 2 x 4 factorial RM ANOVA was performed for average maximal HRs for easy, medium, hard, and long intensity sessions between training groups to determine differences in intensity sessions. Actual maximal intensities did display a significant interaction ($p = 0.015$) between ET and RT groups and a significant main effect ($p = 0.001$) among exercise intensities. A Bonferroni correction factor of $p \leq 0.0125$ was calculated for paired $t$-test comparisons between ET and RT groups for the four exercise intensities. For actual maximal HRs, only the easy intensity session maximal HRs were significantly different ($p = 0.011$) between groups. For maximal HRs, the ET group
averaged 162.35 bpm (± 12.30) and the RT averaged 168.07 bpm (± 10.29) for the easy session. Tables 2 and 3 display the aforementioned results.
**Table 2**

*Exercise Training Prescription: ElliptiGO Training (mean ± SD)*

<table>
<thead>
<tr>
<th>Workout</th>
<th>Easy</th>
<th>Medium</th>
<th>Hard</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prescribed exercise sessions (min)</td>
<td>30 E</td>
<td>10 E</td>
<td>10 E</td>
<td>50 E</td>
</tr>
<tr>
<td>Prescribed frequency (weekly # of sessions)</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Actual completed frequency (weekly # of sessions)</td>
<td>7.91 ± 0.30</td>
<td>4.00 ± 0.00</td>
<td>3.91 ± 0.30</td>
<td>3.91 ± 0.30</td>
</tr>
<tr>
<td>Total prescribed time (min)</td>
<td>30</td>
<td>40</td>
<td>42</td>
<td>60</td>
</tr>
<tr>
<td>Actual total time (h:min:s)</td>
<td>00:31:04</td>
<td>00:41:15</td>
<td>00:42:17</td>
<td>1:00:57</td>
</tr>
<tr>
<td>Prescribed HR range (bpm)</td>
<td>E &lt; 163.6</td>
<td>M = 163.6-178.9</td>
<td>H &gt; 178.9</td>
<td></td>
</tr>
<tr>
<td>Actual average HR (bpm)</td>
<td>145.40 ± 10.33*</td>
<td>158.10 ± 9.77*</td>
<td>154.90 ± 11.38*</td>
<td>149.10 ± 9.57*</td>
</tr>
<tr>
<td>Actual HRmax (bpm)</td>
<td>162.40 ± 12.30*</td>
<td>175.50 ± 10.39*</td>
<td>181.20 ± 9.65*</td>
<td>173.30 ± 10.43</td>
</tr>
<tr>
<td>Actual total distance (km)</td>
<td>10.31 ± 1.32*</td>
<td>14.93 ± 2.39*</td>
<td>15.40 ± 2.65*</td>
<td>21.77 ± 2.82*</td>
</tr>
</tbody>
</table>

*Note.* E = easy M = medium H = hard; all exercise continuous. *Significant different (p < .0125) between ET and RT.
Table 3

*Exercise Training Prescription: Run Training (mean ± SD)*

<table>
<thead>
<tr>
<th>Workout</th>
<th>Easy</th>
<th>Medium</th>
<th>Hard</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prescribed exercise sessions (min)</td>
<td>30 E</td>
<td>10 E</td>
<td>8x1 H</td>
<td>2min E rest</td>
</tr>
<tr>
<td>Prescribed frequency (weekly # of sessions)</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Actual completed frequency (weekly # of sessions)</td>
<td>8.00</td>
<td>4.10</td>
<td>3.82</td>
<td>3.91</td>
</tr>
<tr>
<td>± 1.18</td>
<td>± 0.30</td>
<td>± 0.40</td>
<td>± 0.30</td>
<td></td>
</tr>
<tr>
<td>Total prescribed time (min)</td>
<td>30</td>
<td>40</td>
<td>42</td>
<td>60</td>
</tr>
<tr>
<td>Actual total time (h:min:s)</td>
<td>00:30:58</td>
<td>00:40:19</td>
<td>00:41:19</td>
<td>1:00:08</td>
</tr>
<tr>
<td>Prescribed HR range (bpm)</td>
<td>Easy &lt; 165.7</td>
<td>Medium = 165.7-179.5</td>
<td>Hard &gt; 179.5</td>
<td></td>
</tr>
<tr>
<td>Actual average HR (bpm)</td>
<td>154.20</td>
<td>160.90</td>
<td>161.40</td>
<td>157.90</td>
</tr>
<tr>
<td>± 9.12*</td>
<td>± 9.69</td>
<td>± 9.19</td>
<td>± 10.79*</td>
<td></td>
</tr>
<tr>
<td>Actual HRmax (bpm)</td>
<td>168.10</td>
<td>177.50</td>
<td>184.2</td>
<td>175.10</td>
</tr>
<tr>
<td>± 10.30*</td>
<td>± 11.07</td>
<td>± 9.55</td>
<td>± 11.57</td>
<td></td>
</tr>
<tr>
<td>Actual total distance (km)</td>
<td>5.91</td>
<td>8.00</td>
<td>8.07</td>
<td>11.49</td>
</tr>
<tr>
<td>± 1.10*</td>
<td>± 1.22*</td>
<td>± 1.20*</td>
<td>± 1.78*</td>
<td></td>
</tr>
</tbody>
</table>

*Note. E = easy M = medium H = hard; all exercise continuous. *Significant different (p < .0125) between ET and RT.*
A repeated measures ANOVA displayed no statistically significant differences among time points for all physiological variables (VO$_2$max, AT, RCP, RE and 5,000 m time trial times) except relative ($p = 0.024$) and absolute ($p = 0.010$) AT. This can be seen in Table 4. A post hoc analysis revealed a significant difference between the relative AT values at the initial 40.17 (± 6.47) and PE 42.33 (± 6.96) ($p = 0.024$) and between the initial and PR 41.60 (± 6.15) ($p = 0.035$) time points. This was also seen for absolute AT values between the initial 2.54 (± 0.78) and PE 2.68 (± 0.78) ($p = 0.020$) and initial and PR 2.66 (± 0.80) ($p = 0.009$).
The percent change between training periods was also evaluated using a paired $t$-test to better examine the degree of change in VO$_2$max, AT, RCP, RE and 5,000 m time trial times. These results mimicked the other physiological findings except when

| Table 4 |
|-----------------|--------|---------|---------|
| **Physiological Data (mean ± SD)** | Initial | Post ElliptiGO | Post Run |
| Aerobic Capacity (VO$_2$max) | | | |
| Relative (ml/kg/min) | 57.92 ± 9.68 | 58.89 ± 9.78 | 59.01 ± 9.46 |
| Absolute (L/min) | 3.66 ± 1.11 | 3.75 ± 1.16 | 3.77 ± 1.17 |
| Anaerobic Threshold (AT) | | | |
| Relative (ml/kg/min) | 40.17 ± 6.47 | 42.33 ± 6.96* | 41.60 ± 6.15* |
| Absolute (L/min) | 2.54 ± 0.78 | 2.68 ± 0.78* | 2.66 ± 0.80* |
| Respiratory Compensation Point (RCP) | | | |
| Relative (ml/kg/min) | 51.50 ± 9.49 | 52.81 ± 9.33 | 52.30 ± 9.58 |
| Absolute (L/min) | 3.25 ± 1.01 | 3.36 ± 1.06 | 3.35 ± 1.11 |
| Running Economy (RE) | | | |
| 6 mph (ml/kg/km) | 204.69 ± 17.43 | 202.94 ± 16.28 | 200.46 ± 15.41 |
| 7 mph (ml/kg/km) | 202.40 ± 16.74 | 203.82 ± 14.36 | 197.98 ± 10.55 |
| 5,000 m Time Trial | | | |
| Time (s) | 1303.00 ± 210.05 | 1303.17 ± 224.13 | 1269.00 ± 188.62 |

* Indicates a significant increase ($p \leq .05$) compared with the initial time point.
comparing the percent change for relative and absolute AT. The percent change for relative AT was not significantly different between the initial to PE 3.32 (± 6.35) and from the initial to PR 2.08 (± 7.00) \( (p = 0.714) \). The percent changes for AT initial to AT PE and AT initial to AT PR were 2.97\% (± 6.47) and 1.81\% (± 6.74), respectively. Continually, no significant differences were observed when the percent change between these time points were expressed as absolute values \( (p = 0.738) \).

Participants performed a 5,000 m time trial at the end of each testing period on an outdoor 400 m standardized track. A repeated measures ANOVA showed no significant differences in 5,000 m time trial times \( (p = 0.051) \) among the initial 1303.00 s (± 210.05), PE 1303.17 s (± 224.13), and PR 1269.00 s (± 188.62) time points. These results are seen in Figure 1.
Figure 1. 5,000 m time trial times. Measurements reported at the initial, post- ElliptiGO, and post- run time points.

Utilizing a paired $t$-test and Bonferroni correction factor of $p \leq 0.017$, this non-significant finding was also observed when comparing the percent change pre- and post-each training mode. The percent change was not significantly different ($p = 0.023$) following ET 1.04 ($\pm 2.76$) compared to the percent change following RT - 3.07 ($\pm 3.78$). Below Figure 2 displays this finding.
A Wilcoxon Signed Rank test was used to compare soreness, RPE and enjoyment between ET and RT periods. The median soreness value was taken for comparison from the whole, upper and lower body sections. The medians from each exercise period were then averaged over the entire training period and compared between training periods. Lower body soreness levels were significantly lower for the ET ($Z = -2.40, p = 0.016$) compared to the RT. Whole ($Z = -0.169, p = 0.866$) and upper ($Z = -0.169, p = 0.866$) body soreness levels were not significantly different between ET and RT.

Wilcoxon Signed Rank tests were used to compare RPE values between ET and RT. Participants provided an RPE value corresponding to the highest perceived effort
rating on a scale of 6-20 during the exercise session for whole, upper, and lower body. These RPE values averaged over the entire four week training period. There were no significant differences for whole (Z = - 1.20, p = 0.23), upper (Z = - 0.27, p = 0.79) or lower body (Z = - 0.85, p = 0.398) RPE values between ET and RT.

A Physical Activity Enjoyment Scale (PACES) questionnaire was used throughout the study to determine levels of enjoyment between ET and RT, following the long exercise session each week. A Friedman’s test displayed no significant differences in levels of enjoyment among weeks 1, 2, 3, or 4 for either ET (p = 0.448) or RT (p = 0.064) separately. The four enjoyment values for each week were then averaged to create two overall average enjoyment values for each training period. A Wilcoxon Signed Ranked test displayed no significant differences (Z = - 1.334, p = 0.182) in levels of enjoyment for either ET, 5.08 (± 1.01) and RT 5.43 (± 0.81) groups.

Whole, upper, and lower body RPEs were taken following each VO₂max test and 5,000 m time trial. Using a Freidman test, significant differences were seen in lower body RPE values following the VO₂max tests (χ² = 8.42, p = 0.015). Further post hoc tests were completed using Wilcoxon signed-rank tests with a Bonferroni correction factor; this created a new significance level of p ≤ 0.017. Lower body RPEs were significantly different between the initial 17.72 (± 1.62) and PE GXT 19.09 (± 0.83) (Z = - 2.56, p = 0.011). This can be seen in Figure 3. There were no significant differences (p > 0.017) seen following the 5,000 m time trial for RPE.
Figure 3. RPE values following VO$_2$max test in lower body.*Significantly different from the initial.
Chapter 5: Discussion

This study aimed to investigate the physiological and subjective responses to a 4-week training program using the ElliptiGO compared to a matched run-training program in highly fit, trained runners. This aim was chosen to determine the physiological and subjective effects of the ElliptiGO over a 4-week training period compared to running. The period of 4-weeks was chosen because it corresponds to the typical time away from running due to injury. A typical scenario for this situation is a runner who incurs an injury that prevents all run training prior to the championship race but the runner still aims to compete in the championship race (Tenforde et al., 2012). It is a period of time that has been seen to produce short term detraining effects and has been highly used in previous cross-training research (Bushman et al., 1996; Mujika & Padilla, 2000). For this reason, a 4-week period was chosen as an adequate time for decreases in physiological and performance variables in highly fit trained runners if a training stimulus is able to maintain physiological and performance variables. Men and women were chosen for this study because the same ElliptiGO model is marketed to both genders. Ages among 18-35 were selected because this age group was proposed as an age group when participation in competitive racing is probable. This age group also represented a generally healthy population available in at a university for participation in this study. Also, it was seen that this age group generally did not pose any balance, hearing or vision impairments, all of which would have produced unsafe riding of the ElliptiGO.

An analysis of relative AT at 0, 4, and 8 weeks showed there was no order effect seen in this randomized crossover design study. This indicated that the order of
prescribed training did not influence the results of this study. Total time, distance, and HRs were monitored by a GPS watch and saved for later review for each training period. The recorded average total time and frequency of each exercise session met the required exercise prescription for each training period and did not differ between training periods.

Prescribed exercise intensities were determined by using the corresponding HRs from each participant’s most recent GXT. This was the method for determining relative training intensities for each training period for each participant. HRs were recorded from a HR watch during the GXT every 30 seconds. Prescribed intensity zones were easy (HR < HR at AT), medium (HR range = HR at AT to HR at RCP) and hard (HR > HR above RCP) intensities as determined by the VO$_2$max test. Percentages of prescribed training in these zones were 80%, 15% and 5% for easy, medium and hard, respectively. These ranges were representative of an endurance trained athlete’s training (Esteve-Lanao, San Juan, Earnest, Foster, & Lucia, 2001). This study aimed to design a training program that replicated these known training intensities and volumes.

The prescribed HRs for each intensity zone did not differ between training periods. There was a difference in actual HRs between ET and RT for all exercise sessions; however, actual HRs observed were not considered practically different because participants were able to obtain average and/or maximal HRs associated with each prescribed HR zone for both ET and RT. For example, the easy training zone was prescribed as any HR lower than 163.6 bpm and 165.7 bpm for ET and RT, respectively. The actual average HR for the easy training session for ET was 145.40 bpm ($\pm$ 10.33) and 154.20 bpm ($\pm$ 9.12) for RT. These values were significantly different from one another,
but both were lower than the minimum prescribed HR for the easy intensity zone, indicating during both training modalities participants were able to obtain the prescribed intensity.

A possible trend was seen for ET to elicit lower HRs for each exercise session, especially the significantly lower easy training session and the nonsignificant long training session that included 83.33% easy intensity. The ET average HR for the easy training session was 9 bpm lower compared to RT average easy HR, suggesting that there was a difference between ET and RT for the easy intensity exercise. Researchers postulated that participants exhibited a lower HR during ElliptiGO exercise as a result of low impact nature of the ElliptiGO compared to running. Lower HRs have also been observed between cycling and running at submaximal intensities, (Millet, Vleck, & Bentley, 2009), reinforcing this postulation. Although participants were instructed to continuously move their legs on the ElliptiGO and to avoid coasting, it is possible that participants partially or completely coasted at times during the ET period.

Researchers suggest this as another possible reason for the differences seen in average HRs observed for the easy training sessions. Overall, the recorded HR data provides validity to accept that both training periods were matched for duration, intensity, and frequency due to the fact training frequencies, durations and intensities were not different between training periods. Even though the easy intensity sessions were found to be different they were accepted as easy training for both training periods because the determination of the easy HR intensity zone had been previously established (Esteve-Lanao et al., 2005).
The results of this study allowed researchers to accept the null hypothesis that there would be no significant differences between ET and RT for VO$_2$max, RCP, RE, 5,000 m time trial times over a 4-week training period in highly fit trained runners. Both relative and absolute AT values demonstrated an increase following either training period compared to initial values. These results indicate that both training modalities were effective in increasing AT and maintaining all other physiological variables following either ET or RT exercise training periods. This was expected since researchers designed the training program to increase these physiological and performance variables in highly fit, trained runners over a 4 week training period based on previous research (Midgley, McNaughton, & Jones, 2007). The prescribed training intensities included 80% easy, below AT levels, 15% of exercise within a range between AT and RCP, and 5% high intensity exercise above RCP. This training is representative of the exercise training an endurance trained runner participates in (Esteve-Lanao et al., 2005). This produced maintenance of VO$_2$max, RCP, RE, and 5,000 m time trial time and most notably the increase in AT following either training period. This result was not hypothesized but also was beneficial for validating the ElliptiGO as an effective means for increasing AT with this training program.

The results of this study agree with previous research that has used similar training protocols to elicit physiological changes (Moxnes & Hausken, 2012; Seiler & Tonnessen, 2009) with elliptical exercise. This was also observed in a study researching the effects of a 4-week elliptical training period on recently trained runners (Joubert et al., 2011). However, participants were only recently trained runners of an experience level of
4 weeks. In contrast, this present study used highly fit, trained runners with an average of 10.17 years (± 5.74) running experience. Egana and Donne (2004) observed maintenance of VO\textsubscript{2}max and VEmax using an elliptical trainer. In that study, only moderately trained non-runners were used, and testing was performed on a cycle ergometer and not the sport specific modality of a treadmill. This ElliptiGO study improved upon those limitations by using highly fit, trained runners with an average VO\textsubscript{2}max of 57.92 ml/kg/min (± 9.68).

Beyond VO\textsubscript{2}max, a physiological variable that has been linked to improved run performance is RE and was measured in this ElliptiGO study (Foster & Lucia, 2007). RE is measured by calculating the total VO\textsubscript{2} (ml/kg/min) for the amount of time it takes to run 1 kilometer at a given speed. Runners that utilize less VO\textsubscript{2} (ml/kg/min) over 1 kilometer have better RE measurements. Less oxygen per kilogram of body weight is needed to travel the standardized 1 kilometer distance, creating a more efficient runner. This current study utilized treadmill speeds of 6 mph and 7 mph at a 1% grade for RE. These conservative values were chosen to ensure that the running economy speeds did not surpass a runner’s anaerobic threshold and a steady state could be obtained within three minutes as suggested by Saunders et al. (2004). Other studies have used speeds of 268 m/min or approximately 10 mph (Foster & Lucia, 2007). This speed of 268 m/min is typically used with elite and world class runners and thus was not chosen for this study with runners of lower levels of running ability.

No significant differences were observed for RE among the initial, PE or PR time points at 6 and 7 mph. A possible trend was proposed for RE, in that, RE displayed a slight improvement, or lower VO\textsubscript{2} value, at 7 mph following the RT period and only
maintenance of RE following the ET period. RE has been found to be highly dependent on the neuromuscular capacity of a runner (Nummela et al., 2006). This neuromuscular component of RE has been seen to be related to the ability to produce force or impact into the ground to propel oneself upwards and forward. The ElliptiGO might be limited in this capacity due to the low impact design compared to running. These research findings assist in the understanding for the observed trend of improved RE following RT in this ElliptiGO study. The difference in ground impact forces occurring on the body between RT and ET is quantitatively unknown, but differences are evident based on observed significant differences seen in lower body soreness in this ElliptiGO study. Muscle damage and soreness has been seen to be greater following eccentric muscle action exercise and also is a result of force traveling through the lower extremity from the ground (Eston, Mickleborough, & Baltzopoulos, 1995).

The average time trial time was 1303.00 s (± 210.05), 1303.17 s (± 224.13) and 1269.00 s (± 188.62) at the initial, PE, and PR time points, respectively. Researchers noted a possible practical decrease in 5,000 m times following 4 weeks of RT. On average runners were 34 seconds faster following RT. It is suggested that this improved performance is linked to the difference observed in impact forces during RT via improvements in RE. Participants might have also been able to pace themselves during the 5,000 m time trial having had knowledge throughout the RT period of their training paces and running distances. The lower average HRs observed for the ET might also have contributed to the difference in 5,000 m time trial times.
Research investigating the elliptical trainer has agreed with this possible difference. Over a 5-week period of elliptical training, trained high school runners were unable to maintain 3,000 m run performance as compared to run training (Honea, 2012). The elliptical trainer group became on average 47.7 seconds (± 11.3) slower and the run group became 9.4 seconds (± 8.3) faster. Honea (2012) did not see any differences in VO$_2$max, similar to this study, or LT. The elliptical trainer likely lacks the impact force that occurs while running and further suggests a neuromuscular response difference between running and low impact elliptical motion exercise.

In this ElliptiGO study, the improvement in 5,000 m times following RT was overall 34 seconds or 6.8 seconds per kilometer, compared to only an overall 9.4 seconds or 3.13 seconds per kilometer improvement in 3,000 m times in the study by Honea (2012). Following ET, in the ElliptiGO study, 5,000 m times did not change overall, but in the previous study by Honea (2012), 3,000 m times were 47.7 seconds slower following elliptical training. Both studies used similar easy, medium and hard intensities with a frequency of 5-6 exercise sessions per week. Durations were also similar ranging from 35-70 minutes in the study by Honea (2012) compared to 30-60 minutes in the ElliptiGO study. These comparisons indicated that the ElliptiGO might be better at maintaining distance performance compared to the elliptical in trained runners.

The ElliptiGO study results agree with previous research investigating anti-gravity treadmills and DWR. The antigravity treadmill research was presented as a case study and detailed an elite female runner using the antigravity treadmill for 8 weeks following a pelvic stress fracture. This runner was able to qualify for the NCAA
championships in the 10,000 m run. This case study adds conflicting factors by reporting this female was also using aqua jogging and biking to maintain her fitness and performance levels (Tenforde et al., 2012). Total training details also were not reported, thus it is unknown the effectiveness of the antigravity treadmill for this runner.

A more practical and lower cost option compared to the antigravity treadmill is DWR. Training using only DWR has been seen to maintain one’s fitness and performance in a 2 mile run for up to 6 weeks (Eyestone et al., 1993) and physiological variables (Wilber et al., 1996). However, only Eyestone et al. (1993), used trained and fit runners for their study, however a progressively increased training volume and intensity was used over this time period indicating a significant increase in training volume for participants. This increased training volume could have elicited training adaptations regardless of modality, leading to maintenance in land running ability. The ElliptiGO provided similar results to these previous studies but utilized a randomized crossover design with matched exercise training that improved upon the design of these previous studies. Researchers were able to directly compare each participant to themselves at matched training volumes. It is postulated that the ElliptiGO could allow for an increased training volume without an increase in injury risk due to its low impact nature. Future studies should investigate the benefit of increased training volume using an ElliptiGO, separate or with run training.

During DWR showed similar muscle activation patterns compared to running apart from the gastrocnemius muscle (Masumoto et al., 2013). Elliptical riding is also limited in calf musculature use and is consistent with the inability for the elliptical motion
to allow for ankle plantar flexion (Lu et al., 2007). It is unknown whether these same limitations are found using an ElliptiGO. The ElliptiGO is somewhat similar to an elliptical by sharing the same ellipse foot path motion, but differs from a traditional elliptical machine in several ways. Differences with the ElliptiGO include a variable and longer stride length ranging from 16-25 inches (41-64 cm) compared to a stride length from 16-21 inches (41-53 cm) with traditional elliptical machines. Secondly, the ElliptiGO lacks a fly wheel which lightens the total weight and removes the momentum effects that an elliptical produces. A running specific recovery leg swing was also manufactured for the ElliptiGO. This difference positions the ankle into a more plantar flexed position with the toe pointing towards the ground. This might unweight a rider’s leg while moving in the forward motion producing more reason for differences seen between an ElliptiGO and elliptical.

Additionally, the ElliptiGO’s handlebar height can be adjusted to the height of the rider. This handlebar adjustment improves upon a set handlebar height seen with elliptical trainer machines that have been related to various back issues (Moreside & McGill, 2012). A ElliptiGO can also be ridden over ground, which might increase the muscle activation compared to elliptical riding. Future research is needed to confirm these postulations.

The ElliptiGO also showed significantly lower amounts of lower body soreness for the ET group, suggesting there may be limitations of muscle activity and joint movement, in addition, to lower impact forces occurring. Further research is needed on the kinematic, muscle activity and biomechanical aspects of the ElliptiGO compared to
running and elliptical trainers in order to validate the motion of the ElliptiGO as a running specific outdoor machine.

Subjective differences were investigated by measuring RPE, soreness, and levels of enjoyment during both exercise training periods. The main finding was found when comparing lower body soreness levels. In ET lower body soreness was lower and no differences were seen for whole or upper body soreness between ET and RT. This suggests that participants incurred less post exercise soreness in the lower body during ET. Post exercise soreness following exercise has been linked to eccentric muscle actions following run training (Eston et al., 1995; Ide et al., 2013). In order for a muscle to act eccentrically a lengthening under tension must occur. This occurs during running in order control one’s body against gravity upon contact of the foot and the ground. This impact force pressed into the ground is given back to the foot in contact with the ground. This impact force can equal up to 2.9 times one’s body weight (Nilsson & Thorstensson, 1989). The ElliptiGO eliminates a percentage of one’s body weight and it is postulated that this has caused the difference in muscle soreness between training periods.

A Physical Activity Enjoyment Scale (PACES) questionnaire was used throughout the study to determine enjoyment differences in types of training. This 18-item scale measured enjoyment by asking questions with a ranking scale of 1-7 in a counterbalanced manner. This survey was given at the time directly following the long exercise session at the conclusion of each week. These measurements were taken each week and averaged over the four week training period. Higher scores indicated a higher level of enjoyment. There were no significant differences for either the ET or RT periods
among the four weeks of training. Overall, the level of enjoyment for the ElliptiGO was similar to the enjoyment of running. There are other factors unrelated to the actual exercise training that might influence enjoyment such as music or workout partners (Wininger & Pargman, 2003). These factors were controlled for between training periods to eliminate enjoyment differences due to other factors than the enjoyment of the exercise activity.

This study’s results suggest that similar RPEs can be used when prescribing exercise between the ElliptiGO and running. Using RPE values as means to prescribe exercise has been validated (Glass, Knowlton, & Becque, 1992). Furthermore, there were no differences in either the upper or lower body indicating an equal amount of effort given in each body division compared to running. Oxygen consumption and RPE values have been seen to be similar between a treadmill and elliptical at a self-selected intensity (Brown, Cook, Krueger, & Heelan, 2010). However, in the Brown et al. (2010) study, a significant difference in heart rate was observed between modalities. Heart rates were matched between training periods in this current study and thus there were no observable differences in prescribed heart rate at any intensity between training periods. Some participants did initially report difficulty reaching the heart rate prescribed for the hard interval session on the ElliptiGO during the first week but were able to obtain this heart rate during week two.

One limitation to this study is the inability to control for varying weather conditions that could influence a participant’s RPE, enjoyment, or soreness values (Casa, 1999). All three of these measures were subjective. Furthermore, in the situation when
outdoor exercise was unsafe, participants were permitted to exercise indoors. Indoor exercise has been found to increase levels of effort and decrease enjoyment (Thompson Coon et al., 2011). This study had participants rate their enjoyment on a weekly basis and instructed participants to think of the entire past week when answering the enjoyment survey. Researchers controlled the exercise terrain to a flat bike path which could have influenced these subjective measurements based on the likes of each participant. It was attempted to overcome these limitations by instructing participants to rate the subjective items solely based on their feelings towards the exercise modality and not any other conditions. Future research should examine additional subjective information on the ElliptiGO such as overall running feel or closeness to the running motion of the ElliptiGO compared to running.

In summary, the ElliptiGO was not significantly different between ET and RT for VO$_2$max, RCP, RE and 5,000 m time trial times following 4 weeks of matched exercise training. An increase in AT was observed following either training period. Despite these findings, there were practical differences in the 5,000 m performance and RE between training modalities. RPE and enjoyment did not significantly differ between ET or RT but lower body soreness was displayed as significant. The ElliptiGO was suggested to be of low impact based on this soreness difference. The ElliptiGO also produced matched HRs compared to RT for all exercise intensities. Suggested improvements in running specificity of the ElliptiGO was seen in maintenance of RE and an attenuated decrease in performance measures were also seen compared to the elliptical trainer in previous research (Honea, 2012).
Chapter 6: Conclusions and Future Direction

Forms of cross-training have been unable to maintain physiological and performance variables over time in trained runners (Honea, 2012). This ElliptiGO study displayed that the ElliptiGO can maintain VO$_2$max, RCP, RE, and 5,000 m time trial times, following a 4-week exercise training period in highly fit, trained runners. Additionally, AT was increased following ET. This study utilized a matched randomized crossover design in which participants performed exercise sessions of the same training volume and intensity for both training periods. Future research could investigate the effect of increasing the training volume on the ElliptiGO in conjunction with running to further understand the potential for this exercise machine to be used as a training tool.

Due to the lower levels of muscle soreness seen in this study, participants could potential increase their training volume while incurring less soreness. Participants in this study did not perform any outside exercise beyond what was prescribed. Future research could look at the effects of an ElliptiGO and lifting or ElliptiGO and DWR training protocol. Knowledge on the ElliptiGO’s ability to elicit a VO$_2$max similar to running is also advantageous to validate the claims this machine can produce high intensity, running specific, exercise.

Soreness, RPE, and enjoyment were similar between training modalities except for lower body soreness. This difference was suggested to be due to the low impact nature of the ElliptiGO and lack of eccentric muscle actions occurring while ElliptiGO riding. Future research should investigate the degree of impact force occurring while exercising on the ElliptiGO in order to enable runners and coaches to properly prescribe
ElliptiGO training. This could allow these populations to avoid excessive impact forces that have been linked to overuse injury (Hreljac, 2004). Other research could investigate possible issues or complications with the ElliptiGO for those who train exclusively with this machine. Furthermore, to more fully understand the ElliptiGO, it would be beneficial to understand the muscle activation patterns and kinematics while riding an ElliptiGO. This information would be beneficial to compare this machine to running and the ability for the ElliptiGO to replicate the running motion, as well as how it improves upon the elliptical motion. This study utilized college-aged, healthy, and fit runners. It would be beneficial to see the effects of ElliptiGO training in other populations, such as athletes who are injured, balanced impaired, or older.
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Appendix I: Methodology Design

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<th>Preliminary Screening (Testing Session 1)</th>
<th>24-48hrs</th>
<th>5,000m Time Trial #1</th>
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<tbody>
<tr>
<td>* Informed consent</td>
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<td>* Health History Questionnaire</td>
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<tr>
<td>* Running History Questionnaire</td>
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<tr>
<td>* Anthropometric testing</td>
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<td>* VO_{2}max treadmill test</td>
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<tr>
<td>* Overview of training program</td>
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Random assignment of qualified participants; ElliptiGO familiarization Period

Exercise Training Period 1 (4 weeks)

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<th>Testing Session 2</th>
<th>24-48hrs</th>
<th>5,000m Time Trial #2</th>
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<tr>
<td>* 20 exercise sessions with training 5 days/wk</td>
<td>* Same procedures as Preliminary Screening without questionnaires or consent form</td>
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CROSS OVER (switch groups)

Exercise Training Period 2 (4 weeks)

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<tr>
<th>24-48hrs</th>
<th>Testing Session 3</th>
<th>24-48hrs</th>
<th>5,000m Time Trial #3</th>
</tr>
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<tr>
<td>* Matched training volume with Exercise Training Period 1 with training 5 days/wk</td>
<td>* Same procedures as Treadmill Trial 2</td>
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Note. © 2014 Ian E. Klein
Appendix II: Health History Questionnaire

Health History Questionnaire

Please fill out ALL information. Please PRINT!

**PERSONAL INFORMATION**

- **Name:**
- **Date of Birth:** __/__/____
- **Gender:**
- **Ethnic Group:** Caucasian/Asian/Black/Hispanic (circle as many as apply) Other:
- **Address:**
  - (street)
  - (city)
  - (state)
  - (zip)
- **ID#:**
- **Today’s Date:** __/__/____
- **Age:** (year)
- **Best Phone Number To Contact:** (_______)
- **E-mail Address:**

**MEDICAL HISTORY QUESTIONNAIRE**

I. Please circle one

1. Are you allergic to any food? Yes / No
   - If yes, please specify

2. Are you allergic to any medication? Yes / No
   - If yes, please specify

3. Tobacco use (Mark all those spaces that apply)
   - I now use tobacco. (how much ____________)
   - I do not use tobacco, but I previously have used tobacco regularly. (how long______)
   - I have never used tobacco.

II. For the following medical conditions, circle one of the options. If you have ever been diagnosed with the condition, please specify the number of years ago that the initial diagnosis was made. If you have never had the condition, write never.

1. Cardiovascular condition
   - a. Persistent high blood pressure
      - yes, continues today/yes, but does not exist today/no, since___________
      - Please specify
   - b. Congenital heart condition
      - yes, continues today/yes, but does not exist today/no, since___________
   - c. Heart murmur
      - yes, continues today/yes, but does not exist today/no, since___________
   - d. Mitral valve prolapse
      - yes, continues today/yes, but does not exist today/no, since___________
   - e. Other heart conditions
      - yes, continues today/yes, but does not exist today/no since___________
      - Please specify
   - f. Rheumatic fever
      - yes, continues today/yes, but does not exist today/no since___________
   - g. Pregnancy
      - Is there any possibility that you may be pregnant? Yes/no

2. Organ Conditions
   - a. Blood disorder
      - yes, continues today/yes, but does not exist today/no, since___________
      - Please specify
   - b. Nervous system disorder
      - yes, continues today/yes, but does not exist today/no, since___________
Please specify

c. Gastrointestinal disease
   yes, continues today/ yes, but does not exist today/ no, since
   Please specify

d. Kidney disease
   yes, continues today/ yes, but does not exist today/ no, since
   Please specify

e. Gall Bladder or liver disease
   yes, continues today/ yes, but does not exist today/ no, since
   Please specify

f. Lung disease
   yes, continues today/ yes, but does not exist today/ no, since
   Please specify

g. Cancer
   yes, continues today/ yes, but does not exist today/ no, since
   Please specify

3. Other conditions
   a. Thyroid disorder
      yes, continues today/ yes, but does not exist today/ no, since
      Please specify
   b. Hypoglycemia
      yes, continues today/ yes, but does not exist today/ no, since
   c. Diabetes mellitus (sugar diabetes)
      yes, continues today/ yes, but does not exist today/ no, since
   d. Diabetes Insipidus (increased urination)
      yes, continues today/ yes, but does not exist today/ no, since
   e. Hirsutism (abnormal growth of hair)
      yes, continues today/ yes, but does not exist today/ no, since
   f. Hyperprolactinemia (increased levels of prolactin in the blood)
      yes, continues today/ yes, but does not exist today/ no, since
   g. Epilepsy
      yes, continues today/ yes, but does not exist today/ no, since
   h. Recurrent urinary tract infections
      yes, continues today/ yes, but does not exist today/ no, since
   i. Anorexia nervosa
      yes, continues today/ yes, but does not exist today/ no, since
   j. Bulimia nervosa
      yes, continues today/ yes, but does not exist today/ no, since
   k. Stress fracture
      yes, continues today/ yes, but does not exist today/ no, since
   l. Other condition
      yes, continues today/ yes, but does not exist today/ no, since

4. Recent medical and personal problems. Circle the appropriate response for each item.
   a. Hepatitis
      yes, in last 6 months/ yes, but not in last 6 months/ never occurred
   b. Anemia
      yes, in last 6 months/ yes, but not in last 6 months/ never occurred
   c. Frequent headaches
      yes, in last 6 months/ yes, but not in last 6 months/ never occurred
   d. Frequent indigestion or upset stomach
      yes, in last 6 months/ yes, but not in last 6 months/ never occurred
   e. Injuries
      yes, in last 6 months/ yes, but not in last 6 months/ never occurred
      Please specify

5. Please estimate as closely as possible your use of the following in the past six (6) months.
   a. Aspirin or other non-prescription pain relievers
      daily or almost daily/ several times per month/ several times/ never
b. Prescription pain reliever (e.g., codeine) daily or almost daily/ several times per month/ several times/ never
c. Prescription drugs to relax you (valium, Librium) daily or almost daily/ several times per month/ several times/ never
d. Prescription anti-depressants daily or almost daily/ several times per month/ several times/ never
e. Recreational drugs (e.g., marijuana, cocaine, LSD, heroin) daily or almost daily/ several times per month/ several times/ never
f. Diet or “pep” pills daily or almost daily/ several times per month/ several times/ never
g. Sleeping pills daily or almost daily/ several times per month/ several times/ never
h. Diurectics daily or almost daily/ several times per month/ several times/ never
i. Laxatives daily or almost daily/ several times per month/ several times/ never
j. Medication for indigestion daily or almost daily/ several times per month/ several times/ never
k. Anti-inflammatory drugs (e.g., Motrin, Naprosyn, Indocin) for inflammatory pain daily or almost daily/ several times per month/ several times/ never
l. Anabolic steroids daily or almost daily/ several times per month/ several times/ never
m. Other prescribed medication daily or almost daily/ several times per month/ several times/ never
Please specify
n. Vitamins daily or almost daily/ several times per month/ several times/ never
o. Iron supplements daily or almost daily/ several times per month/ several times/ never
p. Calcium supplements daily or almost daily/ several times per month/ several times/ never
q. Other mineral supplements daily or almost daily/ several times per month/ several times/ never
r. Energy producing products (e.g., amino acids, creatine, protein powder, etc.) daily or almost daily/ several times per month/ several times/ never
s. Birth Control Pills for the past 30 days/ 60 days/ 90 days/ 120 days/ Never

6. Please estimate as closely as possible your use of the following in the past six (6) months.
   a. Alcohol several times/ once daily/ several times/ several times/ rarely or per day per week per month
   b. Coffee several times/ once daily/ several times/ several times/ rarely or never per day per week per month
   c. Tea several times/ once daily/ several times/ several times/ rarely or never per day per week per month
   d. Soft drinks several times/ once daily/ several times/ several times/ rarely or never per day per week per month

7. Circle the following medical conditions that have occurred in your family in the last two generations. Answer the question with respect to your closest genetic relatives: paternal grandfather, paternal grandmother, maternal grandmother, maternal grandfather, father, mother, sister, brother.
   a. High blood pressure yes/ no/ unknown Family member(s)
   b. Heart disease yes/ no/ unknown Family member(s)
   c. Stroke yes/ no/ unknown Family member(s)
   d. Osteoporosis yes/ no/ unknown Family member(s)
   e. Anorexia nervosa yes/ no/ unknown Family member(s)
   f. Bulimia nervosa yes/ no/ unknown Family member(s)

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Appendix III: Running History Questionnaire

ID:

Running History Questionnaire

Please list the best possible answer for the following questions.

1. How many years have you exercised by running?
   a. Is running your primary type of training? YES NO

2. Average number of miles run per week?

3. Average number of runs per week?

4. Average number of high intensity runs per week? (high intensity = running where it is difficult to talk a full sentence)

5. Currently how often do you exercise in a week? Seldom/ 1/2 / more than 3 times

6. How long do you exercise during one exercise session?

7. Please list all types of exercise/ training you are currently doing?

8. Are you most physically active now? Yes / No
   If no,
   a. When were you most physically active?

   b. What type of exercise/ training did you do? (list all)

9. In the past 3 months have you taken more than 6 consecutive weeks off from running?
   YES NO

10. Have you run consistently for the past 2 months leading up to today?
    YES NO

Personal Records
Please list all that apply in the spaces below:
Mile: ___________ 5k: ___________ 10k: ___________
Half marathon: ___________ Full marathon: ___________
Other races: __________________________________________________________________

Please list your most recent race information
Race name: ___________________________________________________________________
Distance: ____________________ Time: ____________________

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