The Gas Exchange Threshold-Lactate Threshold Relationship Across Cycling Fitness Levels

by
Aaron Seipel

A PROJECT

submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Exercise & Sport Science
(Honors Associate)

Presented June 1, 2015
Commencement June 2015

AN ABSTRACT OF THE THESIS OF

Aaron Seipel for the degree of Honors Baccalaureate of Science in Exercise & Sport Science presented on June 1, 2015. Title: The Gas Exchange Threshold-Lactate Threshold Relationship Across Cycling Fitness Levels .

Abstract approved: _____

Anthony Wilcox

Endurance athletes set the intensities of training sessions using blood lactate data from a maximal graded exercise test. Specifically, these intensities are set as a percentage of heart rate (HR) at lactate threshold (LT). Often, however, gas exchange threshold (GET) data is used as a predictor of LT as it is less invasive and less expensive. A correction equation exists to predict LT using GET, but a consistent relationship between the two has not been established. This study (1) examined the previously inconsistent relationship between the V-slope GET method and the Dmax LT method (LT_{Dmax}), and (2) determined if this relationship, as well as the GET vs 1.5mmol increase LT method ($LT_{1.5}$), holds consistent across a range of fitness levels. Thirty-one subjects (mean age 24.3 ± 6.0 years) underwent a maximal graded exercise test, during which blood lactate and gas exchange data were collected. The heart rates associated with LT were determined using the Dmax and 1.5mmol increase methods, while GET was determined using the V-slope method. Repeated measures ANOVA was used to analyze the GET-LT relationship, Bland-Altman plots were used to assess the agreement between the LT and GET HRs, and plots were constructed of the GET-LT difference compared to GET expressed as a percentage of VO_2max ($GET_{\%max}$) and compared to VO_2max. There was no significant difference between GET HR and either of the LT HRs ($P > 0.05$). Bland-Altman plots of the HR differences vs. HR means showed individuals with higher mean threshold HRs experienced GET at a greater intensity than LT_{Dmax} and $LT_{1.5}$; when compared to $GET_{\%max}$, the data showed a similar, albeit stronger, trend. While GET appears equivalent to LT_{Dmax} or $LT_{1.5}$, it cannot serve as a replacement for LT measures in all individuals—comparisons using LT and GET need to

account for training status as well. Moreover, future research should consider inter-individual differences when determining threshold. As this study showed an increased difference between threshold HR measures in more highly trained individuals, it is possible that gas exchange variables are more sensitive to changes in endurance training status than blood lactate variables.

Key Words: Lactate Threshold, Gas Exchange Threshold, Ventilatory Threshold, Dmax, V-slope, Cycling, Heart Rate, Exercise Testing

Corresponding e-mail address: aa.seipel@gmail.com

The Gas Exchange Threshold-Lactate Threshold Relationship Across Cycling Fitness Levels

by
Aaron Seipel

A PROJECT

submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Exercise & Sports Science
(Honors Associate)

Presented June 1, 2015
Commencement June 2015

Honors Baccalaureate of Science in Exercise & Sports Science project of Aaron Seipel presented on June 1, 2015.

APPROVED:

Anthony Wilcox, Mentor, representing School of Biological and Population Health Sciences

Jason Penry, Committee Member, representing School of Biological and Population Health Sciences

Erica McKenzie, Committee Member, representing College of Veterinary Medicine

Toni Doolen, Dean, University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

Aaron Seipel, Author

TABLE OF CONTENTS

INTRODUCTION

Measures of heart rate (HR) or power output (PO) at lactate threshold (LT), allow endurance athletes to set training intensities, quantify training effects, and predict performance. While the exact definition of LT will depend upon how it is calculated, most simply put it can be defined as the exercise intensity associated with an accumulation of lactate in muscle and blood (13). Numerous methods of interpreting blood samples to determine LT exist (23), including maximal lactate steady state (MLSS), set increases in blood lactate concentration (BLC), various fixed BLCs, and additional methods that rely on determining an inflection point along the blood lactate curve. MLSS however, is considered the most accurate and involves blood sampling during multiple constant load tests, wherein MLSS is measured as the maximal PO that can be maintained over a 30-minut period without an increase in BLC greater than 1 mmol/L in the last 20 minutes of the test (6, 7, 13, 28). This avoids reliance on estimation by directly evaluating BLC at various workloads. These methods have obvious drawbacks in that they require blood sampling, can be expensive, and when directly considering MLSS can be particularly time consuming and physically demanding. As such, Wasserman & McIlroy (50) introduced the concept of a gas exchange threshold as a noninvasive means to determine a threshold point describing the transition from aerobic metabolism to a combination of aerobic and sustained anaerobic metabolism. As gas exchange threshold (GET) has been defined by a variety of different methods over the years, confusion regarding its determination during an incremental exercise test is common; however, all measures of GET rely on an increase in CO_2 expiration relative to O_2 consumption, reflecting H^+ being buffered by intracellular HCO_3^- and and thus producing CO_2 and water (31). Similarly to LT, researchers have developed numerous methods

to determine HR and PO at GET, as well as to predict performance, based upon gas exchange measures (2, 5, 31).

There has been extensive research comparing the many threshold measures (2, 3, 5, 14, 16, 17, 21, 25, 41, 44, 47, 53). Despite the fact that many studies have attempted to determine a clear relationship between the different measures, there has been little agreement as to which method most accurately predicts threshold. While much of this can be attributed to the variety of different measures being used, some studies using the same measures of LT and GET have produced contradictory results (16, 21, 41, 47). These studies specifically have all used the V-slope method to determine GET and the Dmax method to determine LT (LT_{Dmax}), which will be discussed in later sections (5, 16). It is important to note that all of these studies have used groups consisting of individuals with relatively uniform training status—typically trained male subjects. Plato et al. (41) proposed a correction equation to determine LT by using GET. Such an equation's reliability cannot be ensured until the GET-LT relationship is confirmed in individuals of varying fitness levels. To our knowledge no studies have examined inter-individual differences in the GET-LT relationship amongst cyclists of various training levels. The only study that has examined how separate threshold measure are related in untrained individuals relative to trained individuals compared MLSS and critical power, neither of which measure gas exchange data (25).

The traditional view of the relationship between LT and GET was that the excess CO_2 expiration that occurs at the onset of GET is the result of protons being released with lactate production, and then being buffered by blood bicarbonate to produce CO_2 (49). Recently however, this mechanism has been challenged (39, 43). While based upon the relationship between lactate accumulation and CO_2 expiration described by Wasserman and colleagues one

would expect LT to occur at a lower intensity than GET this has not consistently been the case (16, 21, 41, 47).

Although LT and GET may occur at a similar exercise intensity, each result from separate mechanisms, rather than one driving the other (39). As such, it is necessary to address factors which may influence these measures independent of one another. The objective of this study is to examine the relationship between GET and two different LT measures and to determine if variability in the GET-LT relationship is related to an individual's fitness level.

LITERATURE REVIEW

LACTATE THRESHOLD

Maximal Lactate Steady State

MLSS is considered the gold standard in determining lactate threshold, and provides the most direct measurement of the exercise intensity at which lactate accumulation occurs (6, 7, 10, 13, 28). By definition, MLSS is the maximum intensity of exercise that can be maintained for 30 minutes without an increase in blood lactate concentration (BLC) of greater than 1 mmol/L in the final 20 minutes (28). As such, MLSS is determined via multiple 30-minute constant load tests wherein BLC is measured every 5 to 10 minutes. The workload to be applied in each test is fine-tuned based upon the results of the preceding test. Therefore, if the individual displayed lactate accumulation in the preceding test, the workload will be lessened; if they did not, the workload is increased (6, 7). This process is repeated until exercise intensity is determined to be just below a level that would result in blood lactate accumulation in the final 20 minutes of the test (45).

From a practical perspective, MLSS has a number of disadvantages in that establishing MLSS can be time consuming, physically demanding, and potentially expensive. As such, a

direct measurement of MLSS is not often used for training purposes (48). However, it has recently be shown to be a highly reliable measure with low day-to-day variability, favoring its use in research settings (29, 48).

Dmax Method

The Dmax method introduced by Cheng and colleagues provides an objective way of determining LT (16). Using a third order curvilinear regression fitted to the plot of BLC vs. VO_2, a straight line is formed connecting the two endpoints of the curve. The point along the curve that provides the maximum perpendicular distance from this line is the LT_{Dmax}. The corresponding HR and PO values at this point can then be determined. LT_{Dmax} has been shown to have high reliability, and, by definition, will always detect a threshold point (54). One study with elite cyclists found a close correlation between LT_{Dmax} and MLSS power output, but low correlation between HR at LT_{Dmax} and HR at MLSS (47). Additional studies with well-trained male and female cyclists have shown power output at LT_{Dmax} to be closely related to MLSS (18, 53). Czuba et al. also found HR at LT_{Dmax} to be significantly different than MLSS, which they suggest could be the attributable to heat and increased catecholamine levels causing HR to increase during MLSS testing. They also noted that there was a strong relationship between increases in lactate concentration, HR, and percent of HR increase in the last 20 minutes of a constant workload MLSS test (18).

1.5mmol/L Increase Method

In addition to the Dmax method, another method that has shown success predicting MLSS is determining the workload where BLC reaches a concentration 1.5 mmol/L above baseline levels ($LT_{1.5}$) (9). The baseline value is taken as the lowest BLC during exercise. When

Grossl and colleagues recently investigated this method compared to MLSS, as determined by multiple constant load tests, they found that $LT_{1.5}$ was not significantly different than HR at MLSS and showed a high correlation with PO at MLSS (28). Currently, there has been less effort spent investigating $LT_{1.5}$ as compared to LT_{Dmax}, however given that $LT_{1.5}$ has been valid in predicting MLSS values and that the nature of the measure does not require an individual to put forth a maximal effort, $LT_{1.5}$ presents a practical method of threshold determination.

GAS EXCHANGE THRESHOLD

Anaerobic Threshold

In 1964, Wasserman and McIlroy first introduced the idea of predicting lactate threshold via gas exchange measures while working with cardiac patients, which they referred to as the threshold of anaerobic metabolism. This point, where an increase in the ratio of expired CO_2 expired to consumed O_2 occurs, was thought to represent the intensity at which lactic acid would begin to accumulate, with blood bicarbonate concentrations subsequently decreasing (50). Further, they suggested that this was the result of protons on the carboxylic acid group of lactic acid dissociating and being buffered by bicarbonate. While the proposed mechanism linking the two phenomena is flawed, as will be discussed in later sections, this anaerobic threshold hypothesis has served as a basis for a number of other gas exchange threshold measures. Since this time, the term ‘anaerobic threshold’ has been widely adopted in the literature to refer to various different threshold criteria. It is more appropriate, however, to refer to these thresholds by the specific criteria being used, since they will not all occur at the same exercise intensities due to different methods of analyzing BLC and gas exchange data (45).

V-Slope Method

The V-slope method of determining GET was introduced by Beaver and colleagues and involves determining an inflection point on the VCO_2 vs. VO_2 curve during incremental exercise (5). Using linear regression analysis, the curve is divided into two lines, and their intersection is deemed the GET. Heart rate and PO at this point can then be determined. Like Dmax, V-slope will, by definition, always yield a threshold value. Due to it being the only gas exchange threshold utilized in the present study, henceforth the term GET will specifically refer to the V-slope method.

LACTATE THRESHOLD-GAS EXCHANGE THRESHOLD RELATIONSHIP

Physiologic Relationship

Establishing a distinct physiologic relationship between LT and GET is partially dependent upon the parameters used to define GET. However, all of the approaches to determine GET rely on determining a point when VCO_2 increases relative to VO_2. Traditionally, this phenomenon has been attributed to the conversion of pyruvate to lactic acid. Due to the carboxylic acid functional group of lactic acid having a relatively low pK_a value, at physiological pH, a proton will readily dissociate. This proton will in turn be buffered by bicarbonate to produce carbonic acid, which will further be converted to carbon dioxide and water upon being catalyzed by carbonic anhydrase (19, 51).

A 2004 review challenged this principle, arguing that the premise of lactic acid production is not supported by fundamental biochemistry (43). Assuming that lactic acid was produced, H^+ would readily dissociate at physiologic pH, as described by the traditional perspective on lactic acid buffering; however, all of the glycolytic carboxylic acid intermediates

have low pK_a values and thus do not possess the necessary H^+ needed to form lactic acid. Instead pyruvate is converted to lactate—an acid salt. Further, not only does lactate formation not produce protons, it plays a role in buffering them. Protons are instead the product of ATP hydrolysis, wherein the phosphate released with ADP formation must be supported by a hydroxide from water (43).

Péronnet & Aguilaniu evaluated the traditional model of lactic acid buffering via bicarbonate (39). Their review pointed out that CO_2 produced as part of aerobic metabolism cannot be immediately expired, but rather will be converted to and stored as HCO^-_3 in the blood. Based upon this, the traditional view of H^+ buffering would require an antiporter to transport HCO^-_3 back into the muscle in exchange with lactate, due to fixed intracellular HCO^-_3 concentrations being too low to provide adequate buffering capacity. No evidence exists in support of such an antiporter; instead, lactate molecules exit the muscle with H^+ via monocarboxylate symporters, with CO_2 produced from intracellular buffering entering the bloodstream separately (39). With this, intracellular bicarbonate buffering capacity clearly plays a large role in determining GET. As such, a lesser reliance on this system could help to offset GET independent of any changes in lactate accumulation. With it having been suggested that bicarbonate, at most, only buffers 18-25% of generated H^+, such a trend would occur with increased reliance on other intracellular buffer systems (32). Additional buffer constituents include phosphocreatine, histidine-related compounds, phosphates, and other proteins (32, 38, 39).

Dmax V-Slope Observed Relationship

Four studies presently exist that have compared LT_{Dmax} and GET measured by V-slope—three performed in cyclists (16, 41, 47) and one performed in rowers (21). Each of these studies

controlled for fitness level, although the training status of subjects between studies showed significant variation. One of these studies which evaluated elite and professional cyclists competing at the international level, was the only one that demonstrated GET occurring at a greater intensity than LT_{Dmax} both in terms of HR and PO measurements (47). It is important to note that this study utilized 30-second stages in this determination, which could lead to LT_{Dmax} values being underestimated if BLC had not had adequate time to equilibrate with muscle lactate concentration (10). The remaining studies appeared to show a lesser difference between LT_{Dmax} and GET in individuals that were highly trained (16, 21) versus those that were not (41), although the magnitude of these differences is difficult to determine due to each study using different measures to quantify the threshold values. Of the four studies, three measured LT using HR, two measured it using PO, two measured it using absolute VO_2, two measured it as a percentage of maximal HR and VO_2max, and one measured it using BLC.

Of the studies described above, the investigation by Erdogan and colleagues was the only one that utilized Bland-Altman analysis in data interpretation (11). In evaluating the HRs associated with GET and LT_{Dmax} the report reveals that their data does not demonstrate good agreement and does not show any particular bias; however, since their study employed a narrow range in fitness levels, it is likely that this lack of agreement is the result of other inter-individual differences. Their Bland-Altman plots of PO demonstrated good agreement with no noticeable bias, however mean absolute threshold PO cannot be considered a reliable marker of fitness in their study due to the wide weight range of study participants (21).

It is worth noting that in a study comparing the effects of two different interval training protocols on LT and GET over a 7-week period, the correlation between LT and GET showed a small improvement with both groups. This study did utilize the V-slope method of determining

GET, but it did not use the Dmax method to define LT (14). While this data cannot provide insight into the GET-LT_{Dmax} relationship, it does lend support to the idea that the mechanisms underlying GET and LT phenomena are independent of one another.

TRAINING ZONES

Once endurance athletes have determined their LT, to effectively utilize this data they can establish different training zones based upon their threshold HR or PO. These zones are set as percentage ranges of LT instead of VO_2max, with between three and seven typically identified (1, 22, 24, 26, 27, 33, 35). The zone that an athlete will train in for any given exercise session will be based on the focus of that session. The goal of establishing and utilizing appropriately set training zones is so that athletes can provide a substantial enough training stimulus to elicit physiologic adaptations, while avoiding the pitfalls of training at too high of an intensity (27, 33). The magnitude of adaptation will vary depending on the amount of time an individual spends in different zones (40).

TRAINING ADAPTATIONS

While physiologic and performance variables will not all change to the same degree with endurance training, training does yield improvements in threshold parameters, VO_2max, maximal cardiac output, muscle glycogen storage, mitochondrial enzyme activity, and muscle capillarization (13, 30, 34, 40).

It can be difficult to separate the impact of factors specifically affecting blood and muscle lactate and proton concentrations, which would affect LT and GET measures respectively, due to the summative effect of biochemical adaptations generated by training. From a macroscopic perspective, it is well established that after training, athletes exhibit a lower BLC at any given

intensity than prior to training (34). This can likely be attributed to an increase in sarcolemmal monocarboxylate transporter (MCT) density promoting improved lactate clearance (10, 30). While improved lactate clearance would suggest a change in LT independent of GET, MCT transporters act as symporters with protons being cleared from muscle cells alongside lactate, and as such will likely affect GET to some degree (39).

Since GET represents intracellular bicarbonate buffering, improvements in buffering capacity independent of bicarbonate would be reflected by an increase in intensity at which GET is documented. Unfortunately, although improvements in buffering capacity with training are described, the improvement of bicarbonate buffering relative to other intracellular buffering mechanisms has not been directly investigated (53). One study reported higher carnosine buffering capacity in 800-meter runners and rowers as compared to marathoners and untrained subjects (38), which may be related to performing more high intensity interval training. More recently, Edge and colleagues examined the effect of two separate training protocols on VO_2max, LT, and overall buffering capacity in recreationally active female subjects. With training volume controlled, the two groups exhibited similar improvements in VO_2max and LT; however, the group that integrated high intensity interval training demonstrated a significantly greater improvement in buffering capacity (25% vs 2%), as measured by titration of pre- and post-intervention muscle biopsies with 10 mM hydrochloric acid (20). Together these results suggest the underlying mechanisms between GET and LT are very likely independent of one another, although the mechanism linking training and increased buffering capacity still requires additional study.

Maximal Oxygen Consumption

By ACSM standards, maximal oxygen consumption (VO_2max) serves as the criterion measure for assessing cardiorespiratory fitness, and is a strong predictor of performance in endurance events. To determine VO_2max, an individual's respiratory gases are collected and analyzed during an incremental exercise test to exhaustion. When the individual exhibits a plateau in oxygen consumption of less than 2.1 mL/kg/min across an increase in workload, the criteria for VO_2max have been met (46). If a plateau in VO_2 does not occur, additional criteria may be used to validate a test result as representative of maximal effort. Most commonly, these criteria are a respiratory exchange ratio (RER) greater than 1.10 and a HR within 10 beats per minute of an individual's age-predicted maximal HR. In many cases however, these latter criteria can either significantly underestimate or fail to identify VO_2max (42). Due to the drawbacks associated with HR and RER criteria, it is recommended that a verification stage be performed during a maximal exercise test in the event that a plateau in oxygen consumption does not occur (36, 42). For this verification stage, once the individual recovers for a 10-minute period, their workload is gradually increased for one minute until reaching one stage higher than their test was terminated at. After two more minutes at this stage, their workload is increased one stage higher, and they must maintain this PO for another two minutes or until volitional exhaustion. If a plateau in O_2 consumption still does not occur, then the verification stage process is repeated a second time.

Despite VO_2max being widely used to measure cardiorespiratory fitness, evidence suggests that its sensitivity to endurance training may stabilize in trained individuals.

Improvements in performance are instead the result of improvements in other parameters aerobic fitness (13, 34). This phenomenon is particularly apparent in highly trained or elite athletes.

Threshold as Percentage of Maximal Oxygen Consumption

While MLSS is considered the gold standard for threshold determination (6, 7, 13, 28), all threshold measures have been shown to be strong predictors of performance, including GET, LT_{Dmax}, and $LT_{1.5}$ (2, 4, 23). As such, it has been suggested that threshold measures may serve as a better index of aerobic fitness than VO_2max (2). This is also related to the fact that both LT and GET measures display a greater response to endurance training than VO_2max, with more highly trained individuals able to maintain a greater percentage of their maximal capacity without accumulation in blood lactate (13, 34).

PURPOSE

With the previously observed relationship between GET and LT_{Dmax} having been inconsistent and with a number of factors that could potentially affect this relationship, the purpose of this study is to establish a more clear relationship between the two measures. As such, the study will (1) examine the relationship between GET and LT_{Dmax}, and (2) determine if this relationship, as well as the GET-$LT_{1.5}$ relationship, hold consistent across a range of fitness levels. Based on the existing literature and the likelihood that GET and LT are driven by separate mechanisms, we expect to observe GET at a lower intensity than both LT measures in all individuals, with highly trained individuals showing a less difference between the threshold measures.

METHODS

EXPERIMENTAL DESIGN

Participants

Thirty-one self-identified cyclists and triathletes volunteered for this study (n = 18 males, n = 13 females, n = 17 cyclists, n = 14 triathletes). Participants came from a range of fitness levels, with GET values ranging from 58 to 93% of VO_2max (mean GET = 80.0 ± 8.5% of VO_2max), and all had some experience training for cycling events (mean cycling time per week = 283 ± 216 minutes). Additional descriptive characteristics of participants are presented in Table 1.

Prior to participating in any testing, subjects provided written informed consent via a document approved by the Oregon State University Institutional Review Board (IRB), and completed a health history questionnaire to determine any risk factors that may limit their ability to complete the testing requirements. Any potential subjects with one or more cardiovascular risk factor were excluded from participating in the study.

Equipment

For descriptive purposes, body composition was determined using a BOD POD Body Composition Tracking System (COSMED, Rome, Italy). Participants performed all testing on their personal bicycle, which was mounted on a Computrainer (RacerMate, Seattle, WA) with tire pressure standardized to 100 psi. Throughout testing, gas exchange data was collected and analyzed via a ParvoMedics TrueMax 2400 metabolic cart (ParvoMedics, Sandy, UT). Heart rate was monitored using a Polar HR monitor (Polar, Lake Success, NY). Blood lactate concentration was tested using a Lactate Pro Analyzer (Cycle Classic Imports, Carlton, NSW, Australia). All

instruments were calibrated prior to each test based upon standards provided by the manufacturer.

Procedures

Prior to testing, each participant's percent body fat was determined. Following this, participants completed one maximal graded cycling test (GXT_{max}), during which both BLC and gas exchange data were collected. All testing was performed in the Oregon State University Human Performance Laboratory between 6am and 12pm, so as to minimize diurnal variations in HR (15). Participants were instructed not to eat or drink within two hours before testing, with the exception of water. Participants were instructed not to exercise in the 24 hours preceding testing. During the test, participants were given the option to listen to music and were verbally encouraged to maximize performance. The only performance measures that they were able to see during the test itself were time and pedaling cadence.

INCREMENTAL TEST PROTOCOL

Prior to mounting their bicycle, participants' resting blood lactate concentration was established. At this point, the Computrainer was calibrated and a 10-minute self-selected warm-up period was allowed. Following warm-up, the Computrainer was recalibrated to account for any changes in tire pressure related to heat generated during the warm-up. Following warm-up and recalibration of the Computrainer, participants were fitted with a nosepiece and mouthpiece connected to the metabolic cart for gas collection.

Starting intensity and stage increments were determined by using each individual's level of training and, if known, their cycling racing category to estimate their relative functional threshold power (FTP) based on the Coggan power profile (Table 2) (1). This value was used to

calculate their absolute FTP. Stage increments were set at 8% of FTP rounded to the nearest 5W (range = 10-25W, mean = 18.8 ± 4.4), and starting intensity was set four stages lower than estimated FTP (range = 50-250W, mean = 153.8 ± 48.1). Each stage was 3 minutes in duration, with fingertip capillary blood being collected and analyzed in the last 30 seconds of each stage, to allow adequate time for muscle produced lactate to enter the blood (10). Immediately prior to increasing intensity for the next stage, each participant's rating of perceived exertion (RPE) was recorded using the Borg scale (12).

Participants were asked to maintain a pedaling cadence between 70 and 100 revolutions per minute (RPM). Throughout the test, participants were verbally encouraged, and if at any point their cadence dropped below 70 RPM, they were given 10 seconds to correct it. If despite continual encouragement, they were unable to recover to 70 RPM, or if the participant indicated that he or she was unable to continue, the test was terminated and they began a cool-down period with light resistance at a self-selected cadence. Immediately following the last stage of the test, additional capillary blood samples were taken and analyzed each minute until a decrease in BLC was observed. Once this decrease occurred, participants were allowed to continue their cool-down for however long they felt necessary.

If the participant achieved a plateau in oxygen consumption of less than 2.1 mL/kg/min between the last complete minute of the test and the final minute of the stage preceding it, their effort was considered to be maximal and their highest minute average of oxygen consumption was recorded as their VO_2max (46). RER and HR were not used as criteria in determining maximal effort, so as to avoid underestimation (36). If this plateau was not achieved, an additional verification stage was required (36). Following a 10-minute cool down, resistance was gradually increased over a 2-minute period to the highest workload reached in the GXT_{max}. This

workload was maintained for 1 minute, after which resistance was increased one more stage and the participant was encouraged to maintain this for a 2-minute period. Oxygen consumption between the final minute of the verification stage was compared to the final minute of the GXT_{max} to determine if a plateau had been achieved. If the participant still did not demonstrate a plateau, the verification protocol was repeated starting from the final workload of the first verification stage.

THRESHOLD DETERMINATION

Lactate Threshold

Blood lactate concentration was tracked throughout the test for determination of LT_{Dmax} and $LT_{1.5}$ (9, 16). This data was recorded in excel along with the corresponding HR and PO values for threshold calculation by the online Lactate-OR application (37). In the event that the lactate data exhibited a sigmoidal curve shape that would prevent a valid LT_{Dmax} calculation by the Lactate-OR software, LT_{Dmax} was calculated by hand (n = 3). Dmax was chosen due to it being an objective and reliable measure of LT, yet still having demonstrated an inconsistent relationship with the GET (18). The increase in BLC of 1.5 mmol/L method was included since it has been shown to be a valid predictor of HR at MLSS (28). As such, both the GET-LT_{Dmax} and the GET-$LT_{1.5}$ relationship had reasonable grounds for evaluation.

Gas Exchange Threshold

Gas exchange data was collected continually throughout the test, and was used to determine GET based on 30 second averaging of gas exchange data (5). This data was analyzed and interpreted for determination of GET by the V-slope method using the software available through the ParvoMedics TrueOne Metabolic Cart system. While many studies that have utilized

the V-slope method of determining GET have relied on one-minute stages, three-minute stages have been shown to yield GET results that are not significantly different (8).

STATISTICAL ANALYSIS

To evaluate the relationships between the HRs associated with GET, LT_{Dmax}, and $LT_{1.5mmol}$, repeated measures ANOVA was used. Agreement was assessed using Bland-Altman plots wherein the difference between GET and LT HR values was plotted against the mean GET + LT_{Dmax} HR and the mean GET + $LT_{1.5}$ HR (11). Additional plots were also constructed, for which the GET – LT differences were plotted against VO_2max and GET as a percentage of VO_2max ($GET_{\%max}$).

RESULTS

Threshold HR values (mean ± SD) for each measure are presented for both males and females in Table 3. There was no significant difference between GET HR and either LT HR measure ($P > 0.05$). Bland-Altman plots of the GET-LT_{Dmax} (Figure 1) and GET-$LT_{1.5}$ (Figure 2) HR differences both demonstrate some degree of bias. In both cases, participants with lower mean threshold HRs experience GET at a lower intensity than LT, and participants with higher mean threshold HRs experience GET at a higher intensity than LT. While this trend is apparent in each case, it is more distinct in the GET-$LT_{1.5}$ plot. Additional plots present the GET-LT_{Dmax} (Figure 3) and GET-$LT_{1.5}$ (Figure 4) HR differences with respect to $GET_{\%max}$. Both plots show distinct uneven bias with lower GETs yielding GET before LT, and higher GETs yielding GET after LT. This bias held when the HR differences were considered within each gender, albeit the trend appeared to be less exaggerated in female participants (Figures 5 and 6) than in males (Figures 7 and 8). As a separate measure of training status, the GET-LT_{Dmax} (Figure 9) and GET-

$LT_{1.5}$ (Figure 10) HR differences were also plotted against VO_2max. This result did not demonstrate any particular bias.

DISCUSSION

The main finding of this study was that on average GET is not significantly different than LT_{Dmax} or $LT_{1.5}$. This is not in agreement with the results of Plato et al., wherein GET was found to occur at a much lesser intensity than LT_{Dmax} for both men and women (41). In fact, our results show a lesser difference between mean GET and LT_{Dmax} HRs than any of the means reported in previous studies, albeit with a significantly greater standard deviation. Unfortunately, with this large standard deviation, the mean values are of little use from a practical perspective, as they could lead athletes to train at too high or low of intensity.

Observation of the Bland-Altman and other plots provides an explanation for this result. More highly trained individuals, as quantified by $GET_{\%max}$, tended to reach GET at higher HRs than LT_{Dmax} and $LT_{1.5}$, while lesser trained individuals demonstrated GET at lower HRs. These findings are in good agreement with past research comparing GET and LT_{Dmax}, in that studies utilizing more highly trained individuals report LT_{Dmax} preceding GET (47) or a closer relationship between the two variables with GET preceding LT_{Dmax} (16, 21). It should be noted that when VO_2max was utilized as an index of training status, this trend did not occur. VO_2max was utilized due to its current status as the gold standard for assessing cardiorespiratory fitness. In this study, in which the population all had some degree of cycling training experience however, VO_2max does not provide as wide of a distribution as $GET_{\%max}$, which could be attributable to VO_2max having stabilized to some extent in moderately trained subjects, as well as in the more highly trained subjects (34). Based on this, it is possible that the lack of bias in

Figures 9 and 10 is related to VO_2max not providing a sensitive enough measure of training status and thus creating a poor distribution.

The distinct change in the relationship between GET and both LT measures with training lends support to the argument that although the two phenomena may be related, they remain independent of one another (39, 43). While the specific training methods of our subjects were not controlled, this relationship could be explained in part by the findings of Edge and colleagues, who found greater improvements in buffering capacity, relative to improvement in LT, with training at workloads above LT (20). In the study described, LT was determined by a modified Dmax method. While it was not explicitly examined, an elementary understanding of the physiologic mechanisms underlying GET would suggest that an improved buffering capacity would offset intracellular CO_2 production, and thus GET. This may particularly be the case if the buffering improvements come from non-bicarbonate sources, as can be the case with high intensity interval training (38). GET being driven by overall buffering capacity as opposed to lactate could explain the findings of Amann et al., wherein GET and ventilatory threshold parameters were found to be better predictors of 40-kilometer cycling time-trial performance than LT measures (2).

For practical purposes, our findings highlight the importance of considering training status in any future studies that require reliable threshold measures. Until training prescription based on GET data is further investigated, an accurate measure of LT will remain valuable for setting training zones. This does not necessarily preclude the use of GET measures as predictors of LT, but it does suggest that the correction equation proposed by Plato, while potentially a useful tool, should be reevaluated and restructured to include a measure of training status (41). We suggest that this measure be based on $GET_{\%max}$, as a measure sensitive to training

adaptations would be necessary to produce valid and reliable results. GET occurring at a lower intensity than LT_{Dmax} and $LT_{1.5}$ in lesser trained individuals, and at a greater intensity in more highly trained individuals suggests that with training GET improvements may occur more rapidly than improvements in LT_{Dmax} and $LT_{1.5}$. Based on this, and given that VO_2max has been shown to stabilize with training, GET appears to be highly sensitive to training adaptations. Additionally, if the correction equation is to be reconstructed, MLSS should be used in place of LT_{Dmax} if at all possible. Due to the challenges of determining MLSS however, $LT_{1.5}$ may also suffice, since it is not significantly different than MLSS (28).

Our results also lead us to caution against individuals simply using GET interchangeably with LT for training purposes. Svehdal and MacIntosh suggested that all threshold measures be determined independently and be labeled as such, given that they will not all yield the same values (45). The significant degree of variation within methods only further articulates this point. However, if threshold measures must be interchanged, GET and LT_{Dmax} appear to be most closely related in moderately well trained individuals with an approximate range in $GET_{\%max}$ from 70 to 80%. GET and $LT_{1.5}$ appear to be most closely related in approximately the same 70 to 80% range. It is possible that $LT_{1.5}$ may be more reliable in this case because even though it showed a distinct trend of GET occurring at lower HRs than LT in lesser trained individuals and at a higher HR than LT in highly trained individuals, the trend was not as dramatic as is seen with LT_{Dmax}.

In comparing GET and LT in a varied population, we hope to have provided some explanation for discrepancies that have been previously observed, while providing direction for further research in this area. While the two phenomena may be related to some degree, observing the relationship change across fitness levels supports the argument that the mechanisms

governing them are not identical. GET data has the potential to be an invaluable training tool, as it is circumvents the disadvantages of LT testing. It is likely however, that its potential will not be fully realized until a more detailed understanding of its relationship with lactate accumulation is established.

Table 1: Descriptive characteristics of participants

	Combined	Male	Female
Age (y)	24.3 ± 6.0	24.7 ± 6.4	23.8 ± 5.7
Height (cm)	175.7 ± 9.6	182.2 ± 5.0	166.6 ± 6.5
Weight (kg)	70.1 ± 8.1	75.0 ± 5.0	63.2 ± 6.3
Body Fat (%)	19.3 ± 8.1	14.0 ± 5.1	26.6 ± 5.3
VO2max (mL/kg/min)	50.4 ± 9.0	56.4 ± 5.6	42.1 ± 5.5
GET (%VO2max)	80.0 ± 8.5	79.1 ± 9.5	81.3 ± 7.1
Racing Experience (y)	4.4 ± 4.1	4.6 ± 3.6	2.4 ± 3.4
Cycling/week (min)	283 ± 216	312 ± 223	244 ± 206

Table 2: Estimated relative FTP values for different cycling fitness levels

	Men	Women
	FT	FT
	6.40	5.69
	6.31	5.61
	6.22	5.53
	6.13	5.44
World class	6.04	5.36
(e.g., international pro)	5.96	5.28
6.09	5.87	5.20
5.40	5.78	5.12
	5.69	5.03
	5.60	4.95
Exceptional	5.51	4.87
(e.g., domestic pro)	5.42	4.79
5.51	5.33	4.70
4.87	5.24	4.62
	5.15	4.54
	5.07	4.46
Excellent	4.98	4.38
(e.g., cat. 1)	4.89	4.29
4.98	4.80	4.21
4.38	4.71	4.13
	4.62	4.05
	4.53	3.97
Very good	4.44	3.88
(e.g., cat. 2)	4.35	3.80
4.44	4.27	3.72
3.88	4.18	3.64
	4.09	3.55
	4.00	3.47
	3.91	3.39
Good	3.82	3.31
(e.g., cat. 3)	3.73	3.23
3.87	3.64	3.14
3.35	3.55	3.06
	3.47	2.98
	3.38	2.90
Moderate	3.29	2.82
(e.g., cat. 4)	3.20	2.73
3.29	3.11	2.65
2.82	3.02	2.57
	2.93	2.49
	2.84	2.40
Fair	2.75	2.32
(e.g., cat. 5)	2.66	2.24
2.75	2.58	2.16
2.32	2.49	2.08
	2.40	1.99
	2.31	1.91
Untrained	2.22	1.83
(e.g., non-racer)	2.13	1.75
2.18	2.04	1.67
1.79	1.95	1.58
	1.86	1.50

Table 3: Mean HR measures for each threshold parameter

	Combined	Male	Female
GET HR	167.84 ± 13.93	164.11 ± 13.65	173.00 ± 13.10
LT Dmax HR	167.32 ± 11.28	164.67 ± 11.08	171.00 ± 10.91
LT 1.5mmol HR	165.87 ± 10.30	162.28 ± 9.86	170.85 ± 9.03

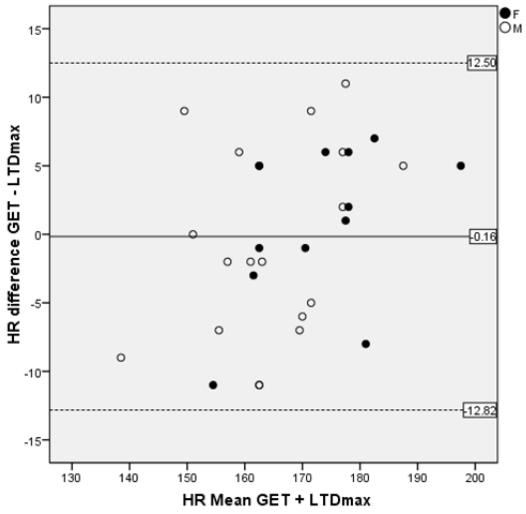

Figure 1: Bland-Altman plot of GET and LT_{Dmax} HRs

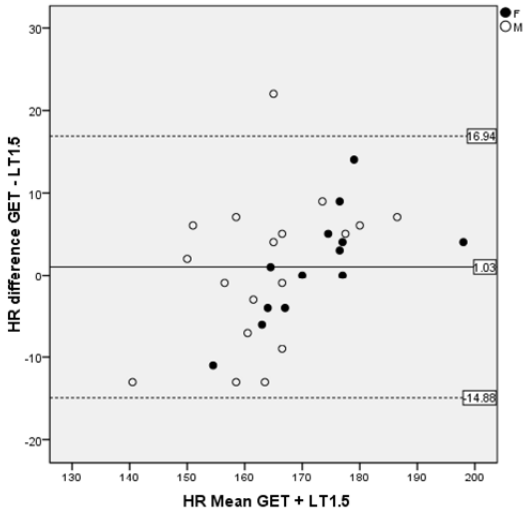

Figure 2: Bland-Altman plot of GET and $LT_{1.5}$ HRs

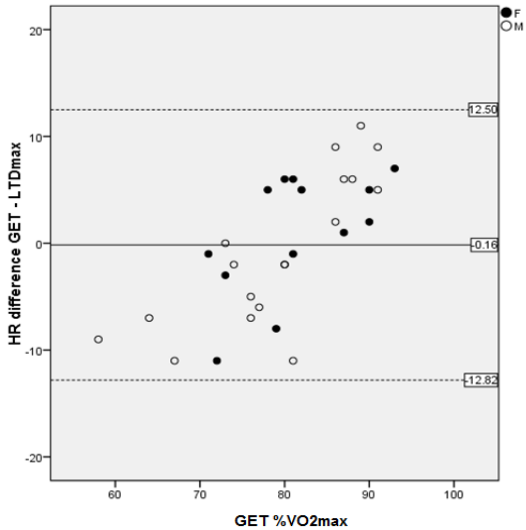

Figure 3: GET-LT_{Dmax} HR difference vs GET

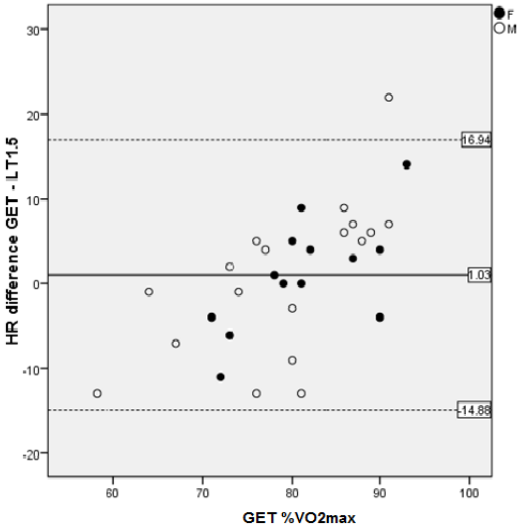

Figure 4: VT-$LT_{1.5}$ HR difference vs GET

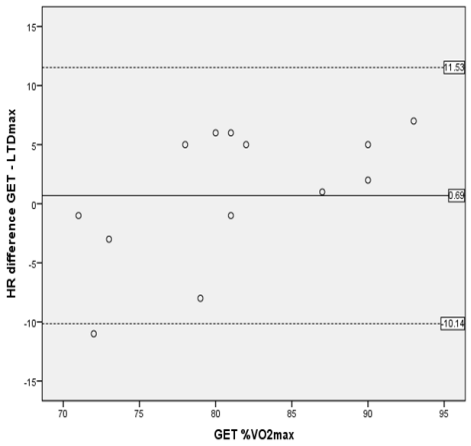

Figure 5: GET-LT_{Dmax} HR difference vs GET for female participants

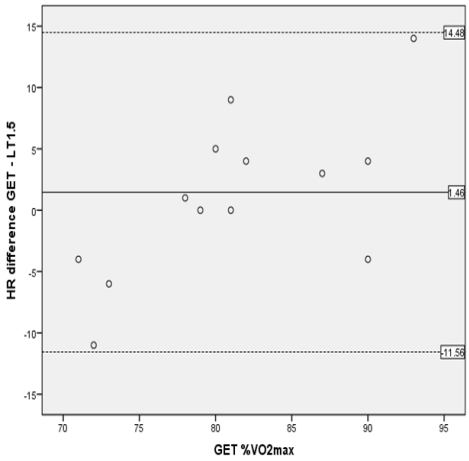

Figure 6: GET-$LT_{1.5}$ HR vs GET for female participants

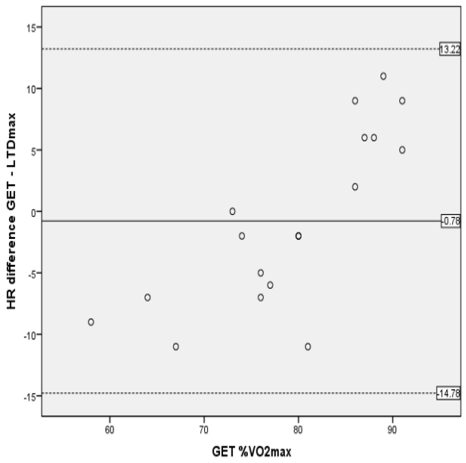

Figure 7: GET-LT_{Dmax} HR difference vs GET for male participants

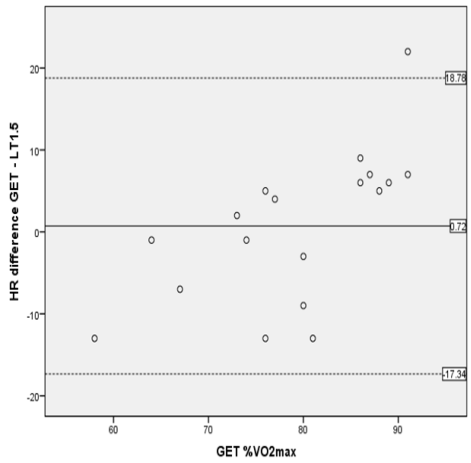

Figure 8: GET-$LT_{1.5}$ HR differences vs GET for male participants

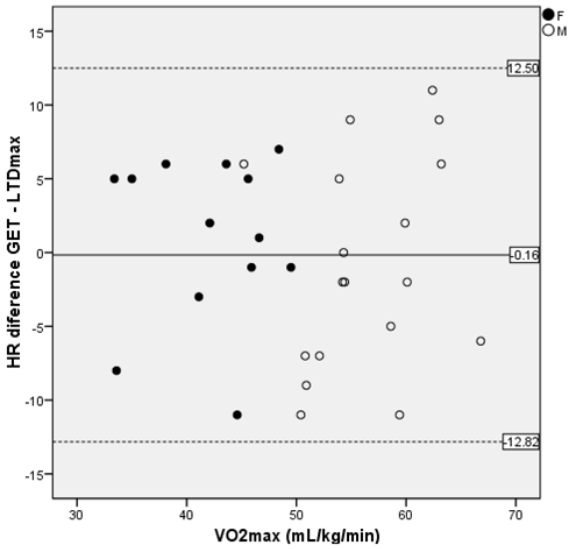

Figure 9: GET-LT_{Dmax} HR difference vs VO_2max

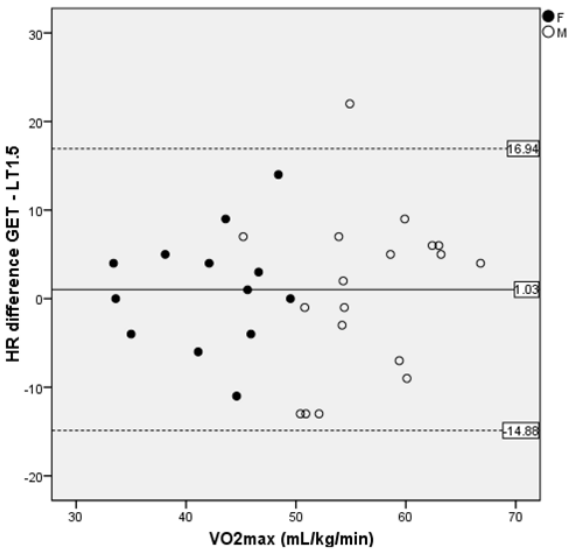

Figure 10: GET-$LT_{1.5}$ HR difference vs VO_2max

REFERENCES

1. Allen H, Coggan A: Training and Racing with a Power Meter. Boulder, CO: VeloPress; 2006.

2. Amann M, Subudhi AW, Foster C: Predictive validity of ventilatory and lactate thresholds for cycling time trial performance. Scand J Med Sci Sports 2006, 16:27-34.

3. Anderson GS, Rhodes EC: Relationship between blood lactate and excess CO_2 in elite cyclists. Journal of Sports Sciences 1991, 9:173-181.

4. Atkinson G, Davison R, Jeukendrup A, Passfield L: Science and cycling: current knowledge and future directions for research. Sports Sci 2003, 21:767-787.

5. Beaver WL, Wasserman K, Whipp BJ: A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol 1985, 60:2020-2027.

6. Beneke R: Maximal lactate steady state concentration (MLSS): experimental and modeling approaches. Eur J Appl Physiol 2003, 88:361-369.

7. Beneke R: Methodological aspects of maximal lactate steady state-implications for performance testing. Eur J Appl Physiol 2003, 89:95-99.

8. Bentley DJ, McNaughton LR: Comparison of W(peak), VO2(peak) and the ventilation threshold from two different incremental exercise tests: relationship to endurance performance. J Sci Med Sport 2003, 6:422-435.

9. Berg A, Jakob E, Lehmann M, Dickhuth HH, Huber G, Keul J: Aktuelle aspekte der modernen ergometrie. Pneumologie 1990, 44:2-13.

10. Billat VL, Sirvent P, Py G, Koralsztein JP, Mercier J: The concept of maximal lactate steady state: a bridge between biochemistry, physiology and sport science. Sports Med 2003, 33:407-426.

11. Bland JM, Altman DG: Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986, 1:307-310.

12. Borg GA: Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982, 14:377-381.

13. Bourdon P: Blood lactate transition thresholds: concepts and controversies. In In, Gore, C (ed), Physiological tests for elite athletes, Champaign, IL, Human Kinetics, 2000, p50-65. Australia2000.

14. Burke J, Thayer R, Belcamino M: Comparison of effects of two interval-training programmes on lactate and ventilatory thresholds. Br J Sp Med 1994, 28:18-21.

15. Carter H, Jones AM, Maxwell NS, Doust JH: The effect of interdian and diurnal variation on oxygen uptake kinetics during treadmill running. J Sports Sci 2002, 20:901-909.

16. Cheng B, Kuipers H, Snyder AC, Keizer HA, Jeukendrup A, Hesselink M: A new approach for the determination of ventilatory and lactate thresholds. Int J Sports Med 1992, 13:518-522.

17. Chicharro JL, Pérez M, Vaquero AF, Lucía A, Legido JC: Lactic threshold vs ventilatory threshold during a ramp test on a cycle ergometer. J Sports Med Phys Fitness 1997, 37:117-121.

18. Czuba M, Zajac A, Cholewa J, Poprzecki S, Waskiewicz Z, Mikotajec K: Lactate threshold (D-max method) and maximal lactate steady state in cyclists. Journal of Human Kinetics 2009, 21:49-56.

19. Davis JA: Anaerobic threshold: Review of the concept and directions for future research. Med Sci Sports Exerc 1985, 17:6-18.

20. Edge J, Bishop D, Goodman C: The effects of training intensity on muscle buffer capacity in females. Eur J Appl Physiol 2006, 96:97-105.

21. Erdogan A, Cetin, Karatosun H, Baydar ML: Non-invasive indices for the estimation of the anaerobic threshold of oarsmen. Journal of International Medical Research 2010, 38:901-915.

22. Faria EW, Parker DL, Faria IE: The science of cycling: physiology and training - part 1. Sports Med 2005, 35:285-312.

23. Faude O, Kindermann W, Meyer T: Lactate threshold concepts: how valid are they? Sports Med 2009, 39:469-490.

24. Friel J: The Triathlete's Training Bible. Boulder, CO: VeloPress; 2006.

25. Greco CC, Caritá RA, Dekerle J, Denadai BS: Effect of aerobic training status on both maximal lactate steady state and critical power. Appl Physiol Nutr Metab 2012, 37:736-743.

26. Gibbons ES: The significance of anaerobic threshold in exercise prescription. J Sports Med Phys Fitness 1987, 27:357-361.

27. Gilman MB: The use of heart rate to monitor the intensity of endurance training. Sports Med 1996, 21:73-79.

28. Grossl T, De Lucas RD, De Souza KM, Antonacci Guglielmo LG: Maximal lactate steady-state and anaerobic thresholds from different methods in cyclists. European Journal of Sport Science 2012, 12:161-167.

29. Hauser T, Bartsch D, Baumgärtel L, Schulz H: Reliability of maximal lactate-steady-state. Int J Sports Med 2013, 34:196-199.

30. Hawley JA: Adaptations of skeletal muscle to prolonged, intense endurance training. Clinical and Experimental Pharmacology and Physiology 2002, 29:218-222.

31. Hoogeveen AR, Schep G, Hoogsteen J: The ventilatory threshold, heart, and endurance performance: Relationships in elite cyclists. Int J Sports Med 1999, 20:114-117.

32. Hultman E, Sahlin K: Acid-base balance during exercise. Exerc Sport Sci Rev 1980, 8:41-128.

33. Jeukendrup A, Van Diemen A: Heart rate monitoring during training and competition in cyclists. J Sports Sci 1998, 16:S91-99.

34. Jones AM, Carter H: The effect of endurance training on parameters of aerobic fitness. Sports Med 2000, 6:373-386.

35. Lucía A, Hoyos J, Pérez M, Chicharro JL: Heart rate and performance parameters in elite cyclists: a longitudinal study. Med Sci Sports Exerc 2000, 32:1777-1782.

36. Mier CM, Alexander RP, Mageean AL: Achievement of VO2max criteria during a continuous graded exercise test and a verification stage performed by college athletes. J Strength Cond Res 2012, 26:2648-2654.

37. Newell J, Higgins D, Madden N, Cruickshank JE, McMillan K, McDonald R: Software for calculating blood lactate endurance markers. J Sports Sci 2007, 25:1403-1409.

38. Parkhouse WS, McKenzie DC: Possible contribution of skeletal muscle buffers to enhanced anaerobic performance: A brief review. Med Sci Sports Exerc 1984, 16:328-338.

39. Péronnet F, Aguilaniu B: Lactic acid buffering, nonmetabolic CO_2 and exercise hyperventilation: A critical reappraisal. Respiratory Physiology & Neurobiology 2006, 150:4-18.

40. Philp A, Macdonald AL, Carter H, Watt PW, Pringle JS: Maximal lactate steady state as a training stimulus. Int J Sports Med 2008, 29:475-479.

41. Plato PA, McNulty M, Crunk SM, Tug Ergun A: Predicting lactate threshold using ventilatory threshold. Int J Sports Med 2008, 29:732-737.

42. Poole DC, Wilkerson DP, Jones AM: Validity of criteria for establishing maximal O2 uptake during ramp exercise tests. Eur J Appl Physiol 2008, 102:403-410.

43. Robergs RA, Ghiasvand F, Parker D: Biochemistry of exercise-induced metabolic acidosis. Am J Physiol Regulatory Integrative Comp Physiol 2004, 287:502-516.

44. Solberg G, Robstad B, Skjønsberg OH, Borchsenius F: Respiratory gas exchange indices for estimating the anaerobic threshold. Journal of Sports Science and Medicine 2005, 4:29-36.

45. Svedahl K, MacIntosh BR: Anaerobic threshold: the concept and methods of measurement. Can J Appl Physiol 2003, 28:299-323.

46. Thompson WR: ACSM's guidelines for exercise testing and prescription. Philadelphia, PA: Lippincott, Williams & Wilkins; 2009.

47. Van Schuylenbergh R, Vanden Eynde B, Hespel P: Correlations between lactate and ventilatory thresholds and the maximal lactate steady state in elite cyclists. Int J Sports Med 2004, 25:403-408.

48. Vobejda C, Zimmermann E: Die maximale konstante herzfrequenz: ein neues herzfrequenzbasiertes verfahren zur abschaetzung der ausdauerleistungsgrenze beim radfahren. / The maximal constant heart rate - a new heart-rate based method for determining the endurance performance limit in cycling. / Frequence cardiaque maximale constante - une nouvelle methode basee sur la frequence cardiaque pour evaluer la limite d'endurance en cyclisme. Leistungssport 2003, 33:4-9.

49. Wasserman K, Beaver WL, Whipp BJ: Mechanisms and patterns of blood lactate increase during exercise in man. Med Sci Sports Exerc 1986, 18:344-352.

50. Wasserman K, McIlroy MB: Detecting the threshold of anaerobic metabolism in cardiac patients during exercise. American Journal of Cardiology 1964, 14:844-852.

51. Wasserman K, Van Kessel AL, Burton GG: Interactions of physiological mechanisms during exercise. J Appl Physiol 1967, 22:71-85.

52. Weekes S, Davie A, Zhou S: Validation of the Dmax method as a predictor of lactate threshold - abstract. In In, Australian Conference of Science and Medicine in Sport, National Convention Centre, Canberra 28-31 October 1996: abstracts, Bruce, ACT, Sports Medicine Australia, 1996, p 444-445. Australia1996.

53. Weston AR, Myburgh KH, Lindsay FH, Dennis SC, Noakes TD, Hawley JA: Skeletal muscle buffering capacity and endurance performance after high-intensity interval training by well-trained cyclists. Eur J Appl Physiol 1997, 75:7-13.

54. Zhou S, Weston SB: Reliability of using the D-max method to define physiological responses to incremental exercise testing. Physiol Meas 1997, 18:145-154.

APPENDIX A

RESEARCH PROTOCOL
1/28/14

1. Protocol Title: "**A Field Test for the Estimation of Heart Rate at Lactate Threshold: The 30-minute Cycling Time Trial"**

PERSONNEL

2. Principal Investigator: Jason Penry PhD (Instructor EXSS; Director Human Performance Laboratory)
3. Student Researcher(s): Staci Partridge BS (MS Student), Aaron Seipel (Undergraduate Honors Student)

4. Investigator Qualifications

Below find the qualifications of each of the research team members, who have professional degrees, and experience in working with human subjects and patients. Collectively they have 18 years experience in the areas of exercise science and exercise testing, thus, are very qualified to work with human subjects and address unforeseen issues if they arise. Research papers and curriculum vitas are available on request to verify the experience and expertise of this research team.

Dr. J. Penry has a PhD in Exercise and Sport Science and is the Director of the Oregon State University Human Performance Laboratory. Over the course of his career, he has independently administered hundreds of VO_{2max} tests, as well as actively participated in many such tests himself. His research experience includes work specific to VO_{2max} testing, including repeated testing of study participants and comparison of field and laboratory test methodologies. As a result of the EMT-B certification that he held in North Carolina, he is trained in emergency procedures that may arise in the performance lab. A former Division I collegiate distance runner and current competitive cyclist, Dr. Penry is also familiar with many of the practical aspects associated with maximal aerobic testing and endurance sport performance. Dr. Penry has trained all student researchers to obtain informed consent and perform exercise testing and interpretation procedures specific to this research question, through both independent study and as part of a quarter-long seminar series for graduate students interested in human performance. Based on his professional training and experience, Dr. Penry is capable of overseeing this project and supervising the students involved in the proposed project.

Ms. S. Partridge is completing her MS degree in Exercise and Sport Science. She has an undergraduate degree in exercise and sport science and has worked at Providence St. Vincent Heart Clinic Cardiology office for 2 years performing diagnostic cardiac maximal exercise stress tests on high-risk patients and those with known coronary disease. She is ACLS certified and has performed over 400 maximal stress tests in the clinical setting. In addition, as part of the requirements for her MS degree, she has completed supervised training in administering VO_{2MAX} tests and other exercise tests in the Oregon State Performance Laboratory under the direct supervision of Dr. Penry. She has since supervised over 30 VO_{2max} tests in the laboratory. Thus, Ms. Partridge has experience working with human

subjects, protecting confidentiality and performing diagnostic and exercise testing. She is also an experienced long-distance triathlete and has assisted in coaching the OSU Triathlon team. With this experience in coaching and having raced triathlons for 10 years, she is very familiar with the study population being used in this project. She will work closely with both Dr. Penry and Mr. Seipel to do all aspects of this research project. She is also trained in the assessment of body composition in the Human Performance Laboratory, which is required for this study. The data from this project will be used for her MS thesis research.

Mr. A. Seipel is completing his HBS degree in Exercise and Sport Science. He has worked as a lifeguard at Dixon Recreation Center for the past 3 years, maintaining current CPR and AED certifications through the American Red Cross. In working as a lifeguard he has had some experience dealing with sudden cardiac emergencies. He has performed over 30 maximal graded exercise tests in the Oregon State Performance Lab so far, and has instructed other undergraduate students in testing protocol under the supervision of Dr. Penry. Thus, Mr. Seipel has experience working with human subjects, protecting confidentiality, and performing exercise testing. In addition, he is an experienced triathlete and has assisted in coaching for the OSU Triathlon team. Having been racing triathlons for the past 4 years, he is very familiar with the study population used in this project. He will work closely with Dr. Penry and Ms. Partridge to do all aspects of this research project. Mr. Seipel will use the data collected in Ms. Partridge's MS thesis research to develop his HBS thesis.

5. Training and Oversight

Dr. Penry will be responsible for the oversight of the study staff, including supervising the student researchers. He will meet with student researchers frequently throughout the study, typically daily during the period of subject recruitment and testing. He will review all participant data with student researchers to assure all issues are address, should they arise. He will also be responsible for ensuring the study ream possesses the necessary skills related to exercise test supervision, for all human subject protections issues, and for the timely and complete submissions of IRB related documents.

All study staff have completed blood pathogen training. Similarly, all study staff have been sufficiently trained and practiced in the techniques and methods required for this study, including but not limited to, blood collection and analysis, maximal graded exercise and $V0_{2max}$ testing and administration of questionnaires. Dr. Penry will work closely with S. Partridge and A. Seipel to assure VO_{2max} testing equipment is functioning properly. Dr. Penry will oversee VO_{2max} assessments. Study team members are already trained on VO_{2max} assessments. Dr. Penry has been doing VO_{2max} assessments in the OSU Exercise Physiology Laboratory over the past 9 years, and maximal testing has been performed in this lab since the 1980s.

FUNDING

6. Sources of Support for this project (unfunded, pending, or awarded)

This research study is funded via the Oregon State University Human Performance Laboratory. It is not externally funded.

DESCRIPTION OF RESEARCH

7. Description of Research

The objective of this study is to access the utility of a field test, the 30-minute cycling time trial, as a means to estimate the heart rate a lactate threshold. It is believed that the time trial will be an acceptable method to estimate heart rate lactate threshold in cyclists and triathletes of all training levels. This research is intended to fulfill the requirements for a Masters thesis and ultimately be published in a peer-reviewed journal.

Aims 1: Establish the validity of the 30-minute cycling time trial in estimating heart rate at lactate threshold. We hypothesize that the average heart rate during the last 20 minutes of the 30-minute cycling time trial will accurately identify the heart rate at lactate threshold as derived from a maximal graded exercise test.

Aim 2: Assess the test-retest reliability of the 30-minute cycling time trial in predicting heart rate at lactate threshold ina test population, as well as the agreement of the test results across a range of aerobic capacities. We hypothesize that the proposed method of identifying heart rate at lactate threshold by the 30-minute cycling time trial will be reliabile and show good agreement across all aerobic capacities.

To achieve these aims, the average heart rate obtained during the last 20 minutes of the 30-minute cycling time trial will be compared to heart rate at lactate threshold as determined during a laboratory-based maximal graded exercise test. The applicability of 30-minute cycling time trial for estimating the heart rate at lactate threshold will be identified across a range of aerobic capacities as described by VO_{2max}.

This research will be used for the thesis of master's student, Staci Partridge, and for the honors thesis of undergraduate student, Aaron Seipel. We plan to submit the research for publication in Medicine and Science in Sports and Exercise Journal (MSSE), or the Journal of Strength and Conditioning Research (JSCR). We will submit an abstract for presentation at the American College of Sports Medicine (ACSM) Annual Meeting.

8. Background Justification

The highest workload an individual can sustain without excessive lactate accumulation is referred to as lactate threshold (LT) (9, 29, 38) or maximal lactate steady state (MLSS) (5, 6, 17, 24). Accumulated data suggest that exercise intensities derived from an individual's LT or MLSS may provide the best indices by which to prescribe guidelines for training (8, 9, 31). After determining the heart rate (HR) or power output at which LT or MLSS is reached, coaches can establish HR or power training zones for an athlete to potentially maximize training adaptations and improve his or her performance (1, 19, 20). The HR or workload at LT is generally found during a maximal graded exercise test (GXT_{max}) while MLSS is generally found after several constant load tests lasting at least 30 minutes (31).

The current gold standard of threshold testing is MLSS. MLSS is most accurately measured in a laboratory setting by collecting blood samples during multiple constant load exercise tests (5, 6, 17, 24). Because of the physical and temporal demand of such testing, researchers identify LT with a single graded exercise test instead (7, 10, 12, 15, 24). A wide variety of protocols exist for single graded exercise tests. The protocol that will be used in this study involves a methodology based on mass, gender and training status. During cycling, the

power that can be achieved depends on ones body weight, gender and training status. The greater the body mass, the more power required to maintain the same speed as someone of a lower body mass. Therefore, power is often expressed in terms of watts per kilogram or W/kg (1). In general, males produce more power than their female counter parts. Highly trained individuals achieve and are able to maintain higher power outputs than less trained individuals of the same gender and weight. Researchers Allen and Coggan (1) have devised a power profile based on gender, mass and training status. This table includes eight levels of training status from untrained to world class professional. Of the power profile, we will focus on the functional threshold power (FTP). FTP is the highest power output that can be maintained for one hour (1). Other researchers have found that HR during a 60-minute cycling time trial is reflective of MLSS (15). Because HR has a linear relationship with power output (3), FTP as defined by Allen and Coggan should be similar to the power at MLSS and LT. This protocol uses the estimated FTP in W/kg based on training status and gender to determine the starting power and incremental increase during a GXT_{max}. The protocol we are using is designed to target the achievement of threshold around minutes 12-15 with maximal test duration of 27 minutes.

Access to laboratory based incremental testing is not always available or feasible and is often expensive. Incremental tests require sophisticated equipment and test administrators specifically trained in the operation of necessary equipment. A need exists for accurate testing protocols that can be used by a variety of test administrators in a non-laboratory environment (9).

Lactate Threshold (LT)

Lactate threshold is the exercise intensity that is associated with a substantial increase in blood lactate during incremental exercise (9, 28, 37). The term LT is also frequently used in lay literature when designing training zones and prescribing workout intensity (1, 19, 20).

The HR and power at LT differ based on the type of exercise being performed. It has been shown that the amount of lactate produced is specific to exercise type and is based on the amount of muscle used during activity (5). For this reason, athletes should identify LT for each different sporting discipline independently.

Like power, HR also varies based on exercise type, however HR_{LT} remains stable over the course of a training season in experienced individuals. In a study by Lucía and others, professional cyclists were tested for HR_{LT} four times over the course of a year during which they experienced four different levels of training ranging from no training to competition efforts. Ultimately, HR_{LT} remained stable between training intensities. It was therefore concluded that one LT test per season should suffice in trained athletes (30).

There are numerous ways to determine LT. In cycling, incremental bicycle ergometer tests are used. In general, the test begins with a warm up followed by incremental increases in workload at a set time interval. During each stage a blood sample is obtained and BLC is recorded. After the subject reaches volitional exhaustion, the test is terminated and the BLC is plotted against workload. The workload at LT is usually defined by power (W), HR or both. Because BLCs vary from day to day and during different types of exercise, more

emphasis is being placed on methods identifying a break point in the lactate curve rather than a pre-determined BLC that is identical across individuals (26, 44).

Identification of Lactate Threshold: After incremental test, a blood lactate curve is plotted. Twenty-five ways to identify the LT were identified in a recent review by Faude and colleagues (17). The 25 concepts of LT identification were categorized into three groups and can be reviewed there (17). Briefly, the first category includes all the methods identifying LT based on a fixed BLC of 2-4mmol/L. As previously discussed, BLC varies day-to-day, but the concept of LT occurring at OBLA or 4.0mmol/L is still commonly used. The second category includes LT concepts that identify the first rise in BLC above baseline concentrations. These concepts have evolved over the years, originally being identified visually, and later being identified by specific increases such as 1.0mmol/L above baseline. The third category includes LT identified by a "rapid/distinct change in inclination the blood lactate curve"(17),which includes the 'D-max' method. Of these concepts, the D-max method has been shown to be both valid and reliable in terms of determining LT and predicting performance.

D-max: In 1992, Cheng and colleagues proposed a model for the determination of VT and LT (10). This model uses a third order curvilinear regression of BLC versus VO_2. Once the regression is fitted to the blood lactate curve, a straight line is formed by the two end points in each curve. The maximum perpendicular distance of that line from the lactate curve represents LT; from there, the workload at LT can be identified. The authors concluded that by using D-max, LT could always be detected. In addition, it has good reproducibility and is an objective method (10). Zhou and colleagues found the HR at D-max to be reliable (ICC of 0.93, $p<0.01$) (44). D-max has also been shown to estimate the workload at MLSS in male and female cyclists with a correlation coefficient of 0.97 ($p<0.05$) (12). In a study headed by Weekes, cycling at 15W above D-max resulted in increasing BLC while cycling at or below D-max workload resulted in a stable BLC (42). In contrast, when the incremental protocol includes stage durations of 6 minutes, it was shown that HR_{LT} found by D-max is not the same as HR at MLSS. To our knowledge, this is the only study that directly compares D-max to MLSS in a longer duration protocol.

Ventilatory Threshold (VT)

In addition to BLC related threshold, another threshold exists which is based on ventilatory parameters and is becoming more widely used due to the noninvasive methodology – ventilatory threshold (VT) (4, 43). VT can be determined in the midst of a VO_{2max} test and requires shorter duration intervals along with shorter test duration. This can make the determination of VT more palatable to the participant. There is still controversy about whether or not this parameter is as good a predictor of performance as those from lactate tests, and little has been done to investigate the training effects of training plans based on HR_{VT}. Even so, some studies have shown HR_{VT} or W_{VT} to be a better predictor of performance than HR_{LT} or W_{LT} (2). This study did not compare HR_{VT} to HR_{LT} from the D-max method. In a meta-analysis comparing VT to LT, it was concluded that the two are not different and therefore VT could be used in place of LT (43). For the purposes of our study, both VT and LT will be identified.

Maximal Oxygen Consumption (VO_{2max})

In an incremental test to volitional exhaustion where respiratory gases are analyzed, VO_{2max} can be determined. VO_{2max} is closely related to performance in endurance events and is used as a way to quantify aerobic capacity. VO_{2max} is achieved when a participant reaches a plateau in minute ventilatory oxygen uptake (VO_2) despite increasing workloads. A plateau is defined as an increase of less than 2.1 mL/kg of oxygen uptake from the previous stage of the incremental test (18). In light of participants seeming to reach maximal exertion, but failing to reach a plateau in oxygen consumption, secondary parameters have been identified to indicate a "true" VO_{2max} in absence of a plateau. Two commonly used parameters are a respiratory exchange ratio (RER) of greater than 1.1 (18), or a maximal HR within ±10 beats of the age-predicted maximum (36). The validity of such parameters has been criticized recently in a study that performed verification of VO_{2max} after the test (36). In the study, only 60% of participants achieved a plateau at their maximal workload. An RER of $\geq$1.1 underestimated VO_{2max} by as much as 27%. Using an RER of $\geq$1.15 lowered that to 16%. Using a HR of HR_{max} ±10 beats also underestimates VO_{2max} and alternatively, excludes those who did reach a true plateau. It was suggested that rather than use secondary parameters to verify a maximal test, that researchers perform a verification stage above the maximal workload in the VO_{2max} test (36). In a more recent study, Meir and others found similar results when using the verification stage following the VO_{2max} test (33). It was concluded that in an absence of a plateau during a VO_{2max} test, that a verification stage should be used to determine the true VO_{2max} rather than using secondary parameters such as HR or RER (33, 36).

Training Zones

In addition to covering miles, athletes are asked to train in HR or power zones based on LT parameters (1, 19, 20). Many training zones have been established over the years, with between three to seven zones based on HR, power, oxygen consumption or BLC (11, 13, 16, 22, 27, 35). The benefits of training in different zones are discussed in detail in Allen and Coggan's book, Training and Racing with a Power Meter. Some of the expected physiological/performance adaptations that occur are increases in plasma volume, muscle mitochondrial enzymes, LT, muscle glycogen storage, muscle capillarization, and stroke volume/maximal cardiac output. The magnitude of adaptation depends on the training zone and time spent in that zone with some of the greatest benefits occurring from training at LT (1). The LT zone ranges from approximately 95-105% of HR_{LT} (1, 19, 20). While training zones based on power and HR are available, the cost of power meters still remains high at $700 to $5000.

Field Testing

Laboratory testing techniques require sophisticated equipment and test administrators specifically trained in the operation of necessary equipment. While a single incremental test is less invasive and time consuming than MLSS testing, access to such resources is not always available or feasible, and is often expensive. In response to the high cost of laboratory performance testing, various field-testing methods have been designed to estimate the HR or power output at which LT is reached.

Due to the lack of environmental control and technical equipment, field tests generally vary more than their laboratory counterparts, and the validity and reliability of such tests should

be addressed (34). Several field tests exist to identify LT or MLSS. Many of these tests are quite detailed and some require access to specific equipment that may not be available to the general public. Available field tests include the 8-minute test (21), incremental test in a velodrome (23), 5-kilometer time trial + 30-minute time trial (25, 38), 40-kilometer time trial (25), maximal constant heart rate test (40, 41), and the 30-minute cycling time trial (30CTT) (20). Of the currently available field tests, the 30-minute cycling time trial (30CTT) is widely recommended and used for identifying HR_{LT}, determined by documenting HR_{avg} over the last 20 minutes of a maximal steady state exercise bout (20). The advantage of this model is the simplicity of the protocol during a single testing session to determine the HR parameters by which an athlete will train. Although this method has been shown to be valid in determining the HR_{LT} in runners (32), the **gap in knowledge** is that the **validity and reliability** of this method for cyclists and triathletes is **unknown**.

The question of validity is confounded by the potential variation depending on aerobic capacity. Some 30-minute time trial methods have been recommended only for experienced athletes (41) while others such as the 30CTT used by Friel (20) are recommended for all levels. Denadai and others investigated the effect of aerobic capacity on the validity of anaerobic threshold for determination of MLSS in cycling and found that the estimate does not depend on level of training (14).

This information coupled with the specificity of LT to the muscle groups used and the type of exercise (5) indicates the need to validate this popular field method. If this method is shown to be accurate, it will allow athletes to estimate HR_{LT} with a single test and a commercially available HR monitor.

Limitations

In selecting individuals who already have experience in exercise testing and competition, there may be participant bias with the 30CTT. This is not considered a major limitation because the participants will not be allowed to view their physiological data during the test. Another limitation may be the ability of untrained cyclists to maintain a constant workload during the 30CTT. While they may not be experienced in pacing the variations in HR will be addressed by taking the HR_{avg} over the last 20 minutes of the test. The 30CTT protocol will be specific to stationary indoor cycling, not outdoor. Due to the possible variability of climate and other factors, we have chosen not to investigate the outdoor version of this test. If the stationary protocol is found to be valid and accurate, the next step will be to investigate the reliability of this test when performed in an external environment.

The age range selected for this study will comprise young adults, however it is expected that results can be extrapolated to all ages. Young adults were selected for safety reasons and to minimize cardiovascular risk factors in our participants. Future studies should examine the validity of these testing methods in older populations. The sample size is limited due to time constraints. The number of participants was chosen to achieve a power level of 0.8 with an alpha level of 0.05. We expect to be able to detect a HR difference of 5 bpm or more with this sample size, a difference that is expected to be meaningful to practitioners. Detection of smaller variations in HR would require a considerably larger sample size.

Summary

Many different field tests are employed to determine the heart rate lactate threshold or maximal lactate steady state. Of these tests, one of the least time consuming and simplest designs is the 30-minute cycling time trial. This field test is already widely recommended and used among cyclists and triathletes of all levels. The validity and reliability of this test in this population is unknown. In addition, the repeatability of the test results across aerobic capacities is unknown. This study will provide empirical evidence which practitioners can base training intensity recommendations. If found to be a valid and reliable test in this population, the need for invasive laboratory tests to accurately determine training zones may be reduced and those performing this field test will be able to feel confident in the data they collect. The test would also provide a simple and accurate way to access changes in fitness over time without the use of laboratory equipment, conserving both time and monetary resources. If the method is shown to be valid across fitness levels, practitioners will also have evidence to support the use of this method in novice and competitive athletes. Should this protocol be found to be an invalid method to predict heart rate at lactate threshold, the cycling community will need to determine a different method for estimating this physiological variable.

9. Subject Population and Recruitment

This study will target active males and females between the ages of 18-45y, who are currently engaging in cycling endurance training or competition of all levels. Our goal is to recruit 30 active participants. To meet this goal we may have to screen 50 participants to reach 30 eligible who complete the study based on a 30% attrition rate. The risk level of the target population is low. Women of childbearing age who are not medically sterile will be screened via urine pregnancy test and, if pregnant, will be excluded from the study.

Participants will be recruited through advertisement via flyers, word-of-mouth, EXSS class announcements, and emails to collegiate teams, clubs and local athletic clubs within the Willamette Valley and around Oregon, including Bend, Eugene, Salem, Corvallis, Monmouth and McMinnville (see Appendix A: Recruitment Emails and Appendix B: Recruitment Flyer). The investigators will conduct in-class recruitment. The study-related announcements (such as study title and investigator contact information) or recruitment materials (such as fliers) will be provided to students in EXSS classrooms where the investigator is not also the class instructor. Recruitment methods will permit students to self-identify outside of the classroom so as to maintain confidentiality and minimize the potential for peer pressure. These areas of Oregon are very popular with athletes, including cyclists, and triathletes to train. The cities of Corvallis, Eugene, and Bend have a high population of elite endurance athletes, which will allow us to look at how the 30-minute time trial may be different in an elite population. Recruiting will take place continuously until all positions have been filled. Prospective participants will be given the contact information of the PI and student investigator for scheduling. Potential participants will be scheduled for Visit 1.

This study is limited to active participants because the research questions specifically address a field test that is only used among active cyclists and triathletes. Although youth (<18y) participate in endurance events, a separate, age-specific study would be required, which is beyond the scope of this research. Research using children would need to address the confounding effect of growth and development on outcome variables. Participants over 45

years of age will not be included in the study to eliminate menstrual irregularities due to perimenopause and aging, as well as additional risk factors for cardiac disease in males. Some minority groups or subgroups will be poorly represented because the geographical location (Willamette Valley and Central Oregon) of the study has only limited numbers of these minority groups who would be eligible for the study. Non-English speaking participants will be excluded from this project because the research team only speaks English and materials are provided only in English.

Subjects will be invited to participate if they meet the following Inclusion criteria:

1) Between the age of 18-45y
2) Experience in training for and/or competing in endurance cycling events.

Subjects will be excluded from the study if they meet any of the following exclusion criteria:

1) Have any risk factors from section 1 or have more than 1 of the cardiovascular risk factors listed in section 2 of the IRB-supplied health history questionnaire (See Appendix C: Health History Questionnaire).
2) Are pregnant, or are planning to become pregnant during the course of her participation in the study
3) Are planning to change training status during the scheduled testing period
4) Are injured
5) Are unable to attempt a maximal test

10. Consent Process

Upon the first visit, prior to engaging in any study activities, a verbal description of the study will be given by one of the researchers. At this time, we will discuss the criteria for participation and let them know that additional information they provide on the questionnaires may make them ineligible for study participation. This will allow potential participants to learn more about the study and ask questions before signing the consent form. The participants will be given ample opportunity to review the consent document and ask the researchers any questions prior to signing the document. Asking the potential participant the following questions will assess comprehension of the informed consent process:

- What questions can I answer for you?
- So that I am sure that you understand what the study involves, would you please tell me what you think we are asking you to do?
- In your own words, can you tell me what the biggest risk to you might be if you enroll in this study?

After the potential participant has had their questions answered, both the potential participant and researcher will sign the informed consent document. The informed consent process will take place in a private room with only the potential participant and researchers present in order to maintain privacy and confidentiality.

We will not enroll children in this study. We will not enroll non-English speakers (e.g. researchers only speak English and all materials are in English) or adult subjects with diminished capacity to consent. We do not anticipate any significant new findings to affect subjects' willingness to participate in the research study.

11. Eligibility Screening

Participants screening will include health history including cardiovascular medical history, symptoms, other health issues and cardiovascular risk factors. Please see the IRB-supplied Health History Questionnaire and the supplemental health questionnaire (Appendices C and D).

Prior to the first visit to the study site, self-eligibility will be assessed via email to determine if participants meet inclusion criteria (see Appendix A: Recruitment Materials- Email Eligibility Self-Screener). We will use a separate, private, password-protected email address that only the aforementioned researchers have access to in order to self-screen potential participants. Using this private email, we will send the eligibility-screening questionnaire to potential participants who will self-determine if they meet the inclusion criteria (see Appendix A: Recruitment Materials- Email Eligibility Self-Screener). If a potential participant self-identifies that they are eligible, they will notify us by phone or email and we will set up a meeting with them for further screening. Non-English speaking persons will be excluded from this project because study team members only speak English and all study materials are in English.

12. Methods and Procedures

Prior to If the participant indicates he/she has greater than mild pain before initiating a testing bout, or gives indication of other variables that may interfere with optimal testing experience, that session will be rescheduled before the end of the four-week test period.

Instruments: To assess gas exchange, a ParvoMedics TrueMax 2400 metabolic cart (ParvoMedics, Sandy, UT), will be used. HR will be monitored using a Polar HR monitor (Polar, Lake Success, NY). The participants' personal bicycles will be set up on a CompuTrainer (RacerMate, Seattle, WA) for all tests. Blood lactate concentrations will be assessed using a Lactate Pro Analyzer (Cycle Classic Imports, Carlton, NSW, Australia).

Overview: Each individual will visit the lab on three to four occasions and will complete three tests in random order: one cycling graded exercise test, and two 30-minute stationary cycling time trials. The first session will include preliminary screening and if desired can be combined with the second session which will include a body composition test and the first randomized test. The third and fourth sessions will include the other 2 tests, again in randomized fashion. Participants will be encouraged to give a maximal effort during each test. Participant total time commitment is approximately 4 hours.

Testing conditions will be maintained at approximately 22 degrees Fahrenheit and approximately 30% humidity. Temperature and barometric conditions will be measured immediately before initiating a testing session. Participants will test between the hours of 6am and 12pm to minimize diurnal variations in heart rate.

Visit 1 (0.5-0.75 h): Informed Consent, Questionnaires

After careful review of participant inclusion/exclusion criteria and discussions with the participant, subjects will sign the informed consent document. Before signing the informed consent, participants will be informed that information provided in the questionnaires might further eliminate them from the study.

Once these procedures are reviewed and informed consent given, the participants will complete a confidential set of questionnaires: Health History Questionnaire, Supplemental Health History Questionnaire. Copies of these questionnaires are in Appendices C and D. The researchers (Penry or Partridge) will confidentially review questionnaires with the participant before they leave to assure completeness of the documents and discuss any issues that may arise. Any issues related to eligibility will be discussed within the research group and reviewed with the participant, if necessary.

Dates will be scheduled for the 2-4 visits.

Participants will be informed of the general consideration and instructions prior to the first exercise test:

General considerations. Participants will be asked to (1) maintain their current activity level, (2) refrain from any exercise for the 24-hour period prior to a testing session, (3) refrain from eating for at least 2 hours prior to the test , and (4) to consume the same meal prior to each test. The above considerations will be verified by interview and a self-report. Participants must wait at least 24-hours between testing bouts. Participants must complete all three tests within a four-week period but will be encouraged to complete testing within two weeks to minimize any training effect that may be present. If they are not able to complete testing within a four-week period, they will be withdrawn from the study. Upon arrival for visits 2-4, participants will be verbally asked if they have met the general considerations. If they have not, the visit will be rescheduled.

Visit 2 (1.5 h): Body Composition Test, Cycling Exercise Test 1

Participants will report to the OSU Human Performance Laboratory (Women's Building, Room 19) in the morning after a 2-h fast and greater than 24-h since their last exercise session. Participants will be verbally asked if they have met the general considerations. Height and weight will be measured using a standard stadiometer and scale, respectively. Body composition will be measured in the BodPod (Cosmed, Sacramento, CA USA). After completion of body composition testing, the first cycling exercise test will be performed. If desired and indicated via e-mail screening, the participant may choose to combine visits one and two.

Visit 3 (1 h): Cycling Exercise Test 2

Participants will report to the OSU Human Performance Laboratory (Women's Building, Room 19) in the morning after a 2-h fast and greater than 24-h since their last exercise session. Participants will be verbally asked if they have met the general considerations. Height and weight will be measured using a standard stadiometer and scale, respectively. The second cycling exercise test will be performed.

Visit 4 (1 h): Cycling Exercise Test 3

Participants will report to the OSU Human Performance Laboratory (Women's Building, Room 19) in the morning after a 2-h fast and greater than 24-h since their last exercise session. Participants will be verbally asked if they have met the general considerations. Height and weight will be measured using a standard stadiometer and scale, respectively. The last cycling exercise test will be performed.

Detailed Methods and Laboratory Procedures

Maximal Graded Exercise Test: This testing will be completed in the Oregon State University Human Performance Laboratory, and will be conducted using a ParvoMedics TrueMax 2400 metabolic cart, a Polar HR monitor and a CompuTrainer. Participants will bring their own bicycles to the lab to ride for the testing. The bicycle will be set up on the CompuTrainer. Tire pressure will be standardized at 100psi. The gas analyzer in the metabolic cart will be calibrated with a known mixture of CO_2 and O_2 prior to each test.

Participants will first complete a warm up and calibration stage. This stage includes steady cycling at a resistance less than the initial resistance of the test for 10 minutes to warm up the bicycle tire to riding temperature. The CompuTrainer is then calibrated according to the manufacturer instructions. After initial warm up and calibration, the participant will be fitted with the mask for collection of expired gasses and a heart rate monitor. Once this procedure is complete, the participant will begin a 3-minute warm-up stage. The wattage of the CompuTrainer during this warm-up stage will be constant. The wattage will be selected to achieve a respiratory exchange ratio (RER) of approximately 0.70 during this warm up phase and will be below the initial wattage of the first stage of the test as determined by body mass, gender and training status of the participant. Individuals will be asked to choose a pedaling cadence that is comfortable to them (between 70 and 100 revolutions per minute (RPM)). Upon choosing a cadence, a metronome will be set at the beats per minute (BMP) to match the selected RPMs. In addition, a cadence sensor will be fitted on the bike and digital RPM will be displayed on the handle bar for the participant to view. The participant will be asked to maintain the selected cadence for the duration of the test. Rating of perceived exertion (RPE) will be assessed at 3-minute increments beginning in the last minute of the warm-up stage.

Following the warm-up period, participants will complete 3-minute constant load stages of increasing workload until volitional exhaustion. The wattage will be increased in each stage by approximately 8% of the participants estimated FTP based on gender, mass and training status to achieve a test length of approximately 18-21 minutes. Test duration may range from 15-27 minutes. HR will be measured using a Polar HR monitor. A finger-stick blood sample

will be collected from a clean dry fingertip at rest, at the end of the warm up period, during the last 30 seconds of each stage and during recovery (1, 3 and 5 minutes) to determine blood lactate concentration. Capillary blood samples will be immediately analyzed using a Lactate Pro Analyzer (Cycle Classic Imports, Carlton, NSW, Australia). The analyzer will be calibrated before each testing session using lactate standards provided by the manufacturer. When the participant indicates that he/she cannot continue or fails to maintain the selected cadence for more than 10 seconds, the test will be terminated. Participants will be allowed to cool down at a self-selected cadence with minimal resistance.

During the cool down phase, VO_{2max} will be assessed. VO_{2max} is achieved if there is a VO_2 plateau evidenced by an oxygen uptake difference of less than 2.1 mL/kg from the previous stage. If a plateau is not achieved, the participants will then perform a verification stage. This will only be done if the participant does not reach a plateau in ventilatory oxygen uptake at the end of the maximal test. After 10-minutes of cool down at minimal resistance, the workload will be gradually increased over a 2-minute period until the final workload of the maximal graded test is reached. After 1 minute, the workload will be increased to 105% of the maximal workload achieved in the maximal graded test. The participants will be encouraged to continue for 2 minutes. The VO_2 plateau will be determined by comparing the final minute of the maximal graded test and the final minute of the verification stage. In the event that a plateau is not demonstrated, a second verification stage will be performed at 110% of the maximal wattage achieved in the maximal graded test. If the participant fails to reach a plateau after the second verification stage, the subject's participation in the study will end.

There are several ways to determine lactate and thereby the heart rate at lactate threshold. The method that will be used in this study is the HR at D-max. This method was chosen for its objectivity and reliability. In addition, the ventilatory threshold will be identified by the V-slope method for comparison of the time trial heart rate to both lactate and ventilatory threshold heart rates.

Results of the VO_{2max} test will be provided to the participants upon completion or withdrawl from the study.

Time Trial: The 30-minute stationary cycling time trial method will be used. Each participant will be fitted with Polar heart rate monitor to collect data. Only lap-time and cadence will be displayed on the monitor. Participants will warm up at a self-selected cadence and workload for 15 minutes. This warm up will include the calibration stage as in the maximal graded exercise test with the exception that the workload will be self selected and not limited to less than the starting workload. After the 15-minute warm up and calibration stage, participants will then begin a 30-minute cycling time trial. The participant will be able to adjust workload throughout the 30-minute cycling time trial; however participants will be blind to their output wattage. They will be asked to cycle near an RPE of 17 and will be asked to provide a maximal, consistent effort for the duration of the 30-minute cycling time trial. Additionally, participants will be fan cooled and allowed to drink cool water as necessary. Heart rate will be monitored continuously. The average heart rate during the last 20 minutes will be used to compare to the heart rate at lactate and ventiatory threshold as determined in the maximal graded exercise test. Ventilatory gases and blood

lactate will not be analyzed during the time trial.

Results of the 30-minute stationary cycling time trial will be provided to the participants upon completion or withdrawl from the study.

Bod Pod: The Bod Pod will be warmed up and calibrated according to the manufactures recommendations. Participants will dress down to tight fitting clothing such as a swimming suit or spandex shorts. Height and weight will be measured using a standard stadiometer and the Bod Pod scale, respectively. Participants will sit quietly in the Bod Pod chamber for approximately one minute at a time for 2-3 tests. Participants will be asked to hold still and breathe normally. Body composition will be calculated based on the standard Siri calculation. Body composition in fat free mass and fat mass will be reported to the participant in percentages and pounds. Questions regarding results will be answered. Participants will be given a copy of this information for his or her own records.

Statistics

Test-retest reliability of the 30-minute cycling time trial will be assessed via Pearson correlation and coefficient of variation.

Agreement of the heart rate at lactate threshold data between the 2 time trials will be examined using a Bland-Altman plot.

Validity of the 30-minute cycling time trial as a tool to estimate heart rate at lactate threshold will be assessed via a two-tailed, paired t-test ($p < 0.05$). The difference in heart rate between the two tests will be graphed across VO_{2max} values to examine how consistantly the test predicts heart rate across aerobic capacities.

13. Compensation

No monetary compensation will be given to those individuals who participate in this study. Participants, however, will receive an assessment of maximal aerobic power and lactate threshold (valued at $90), as well as an estimate of body composition (valued at $40).

14. Costs

Participants will not be charged for any tests that are performed for the purposes of this study. Participants and/or their insurance provider will be responsible for all other medical care expenses. Participants will be responsible for travel costs to the study site.

15. Medical Devices

No medical devices for invasive data collection will be used in this study. We will use Bod Pod for assessment of body composition, and the Lactate Pro Analyzer (Cycle Classic Imports, Carlton, NSW, Australia) will be used to analyze blood lactate concentrations. Blood lactate levels will not be reported to the subjects.

16. Biological Samples

Blood samples via finger stick, totaling 1-2mL or about 20 drops of blood, will be collected from all participants during the maximal graded exercise test to analyze blood lactate concentration and determine lactate threshold. Blood samples will not be retained.

17. Anonymity or Confidentiality

Participants will be described as "Participant" plus participant number (i.e. "Participant 1", "Participant 2", "Participant 3", etc.). All participants' files will be identified by "Participant" plus number or "P" plus participant number. Their names or any information that will readily identify them will not be used in any published data. Should any responses to demographic questions potentially lead to an individual participant being identifiable, we will not report this information in any published data. An electronic document containing a link between identifiers and coded data will be retained with the PI until the study is complete and articles published (5y). Signed consent forms will be stored separately from coded data. All data will be securely locked in Women's Building 19.

Data will be kept in securely locked file cabinets. Any information collected via written, paper questionnaires will be store in a securely locked cabinet in Women's Building 19 after it has been saved electronically using participant code numbers (no names). Paper questionnaires will only have participant code numbers on the documents. All individual identifiers will be removed. Electronic data will be kept on a password-protected computer, securely locked in Women's Building 19 or with the PI in a locked office (Women's Building 207B). The only people that will have access to this data and information will be the research team. All data, including written, paper questionnaires and the electronic document containing a link between identifiers and coded data, will be retained for a minimum of five years after study completion. Once manuscripts are published (5y) all paper data will be destroyed. Electronic unidentifiable (no names only participant code numbers) data will be retained with the PI for another 3y.

18. Risks

The risks of VO_2max testing are as follows:

- Acute exercise may present a risk of untoward events, including sudden death
- Cardiovascular event (i.e., heart attack or cardiac arrhythmia)
    - Overall risk of cardiac events is about 6 events per 10,000 tests
- Serious injury
- Falling
- Physical discomfort
- Fatigue
- Muscle aches, cramps, joint pain
- Muscle strain and/or joint injury
- Delayed muscle soreness
- Abnormal blood pressure/heart rate
- Shortness of breath

- Lightheadedness, fainting
- Dizziness
- Nausea

Every test will be monitored by a member of the research team that has completed the required training to administer and interpret these tests. Tests will be terminated if a study participants exhibits:

- Onset of angina or angina-like symptoms
- Shortness of breath, wheezing, leg cramps or claudication
- Signs of poor perfusion: light-headedness, confusion, ataxia, pallor, cyanosis, nausea or cold/clammy skin
- Failure of heart rate to increase with increased exercise intensity
- Noticeable change in heart rhythm
- Physical or verbal manifestations of severe fatigue

Additionally, the test will be terminated if:

- Participant requests to stop
- The testing equipment fails

The risks of finger stick blood draw are as follows:

- The participant may experience pain when the lancet goes into his or her finger. Other than this momentary pain, the discomfort of a finger stick should be minimal.
- A small amount of bleeding under the skin may produce a bruise (minute hematoma)
- The puncture site may be visible and sore to the touch for a short period of time after the collection.

The risks of body composition testing are as follows:

- Participants may experience claustrophobia during the measurements that use the Bod Pod. There is a button at the knee of the participant while they are inside the Bod Pod that will allow them to open the door of the Bod Pod immediately. A window on the Bod Pod will allow participants to see and communicate with the investigator.
- There is no physical danger involved with these measurements. Room air is continuously circulated through the Bod Pod compartment when it is closed. The compartment does not lock and the person inside can exit at any time.

Emergency procedures include an automatic external defibrillator (AED) located in the same room as the testing equipment and an emergency action plan on file with the department. The study team is trained in the use of the AED and the equipment is regularly inspected to ensure its function. The study team will also be familiarized with the emergency procedures should an event arise.

All gas analysis equipment will be sterilized using a wide-spectrum antimicrobial disinfectant (Cidex). Equipment that cannot be sterilized using this disinfectant will be cleaned using detergent and water.

Test administrators involved with blood lactate testing will use appropriate protection, including, but not limited to, disposable nitrile gloves and eye protection.

Laboratory surfaces will be cleaned using disinfectant wipes.

19. Benefits

Participants will receive a measure of both maximal aerobic power and body composition as a result of participating in this study. In addition, participants will receive several estimates of their threshold heart rate and power that may be used for prescription of training intensities for maximizing adaptations to endurance training.

Benefits to society include the improvement of a common field test used for prescribing exercise intensities for endurance training that includes a cycling component. The identification of test utility across fitness levels will allow for the 30-minute cycling time trial to be used in beginner populations who may not have access to laboratory fitness testing. As such, by providing an accurate tool for assessment, coaches and practitioners can advocate for entry into endurance sport for mildly trained individuals, potentially improving the health of the community.

20. Assessment of Risk:Benefit ratio

Participants will experience short-term fatigue when completing the 30-minute cycling time trial or the maximal graded cycling exercise test. The fatigue is similar to that felt after biking a 12-mile race for the cycling time trial test, and similar to that following a 8-mile race for the graded exercise test. There is a very remote chance that individuals may suffer a heart attack during these maximal efforts, although this will be a very low risk for the study participants, since the pre-screening will have determined them to be physically active and apparently healthy.

The continued development of a field test to determine useful training parameters among exercise enthusiasts is important, as it will 1) allow individuals to test training variables using their own equipment, which is less expensive than laboratory methods; and 2) allow indivdiuals to test such variables in a more easily-accessible method outside the laboratory environment, permitting individuals to perhaps test these variables more regularly; and 3) encouraging individuals intimidated by the laboratory environment to assess these useful physiological variables, perhaps broadening the participant base for cycling-based activities that can be included as part of a healthy lifestyle.

References

1. Allen H, Coggan A: Training and Racing with a Power Meter. Boulder, CO: VeloPress; 2006.

2. Amann M, Subudhi AW, Foster C: Predictive validity of ventilatory and lactate thresholds for cycling time trial performance. Scand J Med Sci Sports 2006, 16:27-34.

3. Arts FJ, Kuipers H: The relation between power output, oxygen uptake and heart rate in male athletes. *Int J Sports Med* 1994, 15:228-231.

4. Beaver WL, Wasserman K, Whipp BJ: A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol (1985) 1986, 60:2020-2027.

5. Beneke R: Maximal lactate steady state concentration (MLSS): experimental and modeling approaches. Eur J Appl Physiol 2003, 88:361-369.

6. Beneke R: Methodological aspects of maximal lactate steady state-implications for performance testing. Eur J Appl Physiol 2003, 89:95-99.

7. Bentley DJ, McNaughton LR: Comparison of W(peak), VO2(peak) and the ventilation threshold from two different incremental exercise tests: relationship to endurance performance. J Sci Med Sport 2003, 6:422-435.

8. Billat VL, Sirvent P, Py G, Koralsztein JP, Mercier J: The concept of maximal lactate steady state: a bridge between biochemistry, physiology and sport science. Sports Med 2003, 33:407-426.

9. Bourdon P: Blood lactate transition thresholds : concepts and controversies. In In, Gore, C (ed), Physiological tests for elite athletes, Champaign, IL, Human Kinetics, 2000, p50-65. Australia2000

10. Cheng B, Kuipers H, Snyder AC, Keizer HA, Jeukendrup A, Hesselink M: A new approach for the determination of ventilatory and lactate thresholds. Int J Sports Med 1992, 13:518-522.

11. Coen B, Schwarz L, Urhausen A, Kindermann W: Control of training in middle- and long-distance running by means of the individual anaerobic threshold. Int J Sports Med 1991, 12:519-524.

12. Czuba M, Zajac A, Cholewa J, Poprzecki S, Waskiewicz Z, Mikotajec K: Lactate Threshold (D-Max Method) and Maixmal Lactate Steady State in Cyclists. vol. 21. pp. 49-56: Journal of Human Kinetics; 2009:49-56.

13. Dalleck L, Bushman TT, Crain RD, Gajda MM, Koger EM, Derksen LA: Dose-response relationship between interval training frequency and magnitude of improvement in lactate threshold. Int J Sports Med 2010, 31:567-571.

14. Denadai BS, Figueira TR, Figuera TR, Favaro OR, Gonçalves M: Effect of the aerobic capacity on the validity of the anaerobic threshold for determination of the maximal lactate steady state in cycling. Braz J Med Biol Res 2004, 37:1551-1556.

15. Dumke CL, Brock DW, Helms BH, Haff GG: Heart rate at lactate threshold and cycling time trials. J Strength Cond Res 2006, 20:601-607.

16. Faria EW, Parker DL, Faria IE: The science of cycling: physiology and training - part 1. Sports Med 2005, 35:285-312.

17. Faude O, Kindermann W, Meyer T: Lactate threshold concepts: how valid are they? Sports Med 2009, 39:469-490.

18. Franklin BA: ACSM's guidelines for exercise testing and prescription. Philadelphia, PA: Lippincott, Williams & Wilkins; 2000.

19. Friel J: The Triathlete's Training Bible. Boulder, CO: VeloPress; 2006.

20. Friel J: Your Best Triathlon. Boulder, CO: VeloPress; 2010.

21. Gavin TP, Van Meter JB, Brophy PM, Dubis GS, Potts KN, Hickner RC: Comparison of a field-based test to estimate functional threshold power and power output at lactate threshold. J Strength Cond Res 2012, 26:416-421.

22. Gilman MB: The use of heart rate to monitor the intensity of endurance training. Sports Med 1996, 21:73-79.

23. González-Haro C, Galilea PA, Drobnic F, Escanero JF: Validation of a field test to determine the maximal aerobic power in triathletes and endurance cyclists. Br J Sports Med 2007, 41:174-179.

24. Grossl T, De Lucas RD, De Souza KM, Antonacci Guglielmo LG: Maximal lactate steady-state and anaerobic thresholds from different methods in cyclists. European Journal of Sport Science 2012, 12:161-167.

25. Harnish CR, Swensen TC, Pate RR: Methods for estimating the maximal lactate steady state in trained cyclists. Med Sci Sports Exerc 2001, 33:1052-1055.

26. Hauser T, Bartsch D, Baumgärtel L, Schulz H: Reliability of maximal lactate-steady-state. Int J Sports Med 2013, 34:196-199.

27. Jeukendrup A, VanDiemen A: Heart rate monitoring during training and competition in cyclists. J Sports Sci 1998, 16 Suppl:S91-99.

28. Karlsson J, Jacobs I: Onset of blood lactage accumulation during muscular exercise as a threshold concept. I. Theoretical considerations. Int J Sports Med 1982, 3:190-201.

29. Kindermann W, Simon G, Keul J: The significance of the aerobic-anaerobic transition for the determination of work load intensities during endurance training. Eur J Appl Physiol Occup Physiol 1979, 42:25-34.

30. Lucía A, Hoyos J, Pérez M, Chicharro JL: Heart rate and performance parameters in elite cyclists: a longitudinal study. Med Sci Sports Exerc 2000, 32:1777-1782.

46.5 Mann T, Lamberts RP, Lambert MI: Methods of prescribing relative exercise intensity: physiological and practical considerations. *Sports Med* 2013, 43:613-625

31. McGehee JC, Tanner CJ, Houmard JA: A comparison of methods for estimating the lactate threshold. J Strength Cond Res 2005, 19:553-558.

32. Mier CM, Alexander RP, Mageean AL: Achievement of VO2max criteria during a continuous graded exercise test and a verification stage performed by college athletes. J Strength Cond Res 2012, 26:2648-2654.

33. Penry JT, Wilcox AR, Yun J: Validity and reliability analysis of Cooper's 12-minute run and the multistage shuttle run in healthy adults. J Strength Cond Res 2011, 25:597-605.

34. Philp A, Macdonald AL, Carter H, Watt PW, Pringle JS: Maximal lactate steady state as a training stimulus. Int J Sports Med 2008, 29:475-479

35. Poole DC, Wilkerson DP, Jones AM: Validity of criteria for establishing maximal O2 uptake during ramp exercise tests. Eur J Appl Physiol 2008, 102:403-410.

36. Svedahl K, MacIntosh BR: Anaerobic threshold: the concept and methods of measurement. Can J Appl Physiol 2003, 28:299-323.

37. Swensen TC, Harnish CR, Beitman L, Keller BA: Noninvasive estimation of the maximal lactate steady state in trained cyclists. Med Sci Sports Exerc 1999, 31:742-746.

38. Van Schuylenbergh R, Vanden Eynde B, Hespel P: Correlations between lactate and ventilatory thresholds and the maximal lactate steady state in elite cyclists. Int J Sports Med 2004, 25:403-408.

39. Vobejda C, Fromme K, Samson W, Zimmermann E: Maximal constant heart rate--a heart rate based method to estimate maximal lactate steady state in running. Int J Sports Med 2006, 27:368-372.

40. Vobejda C, Zimmermann E: Die Maximale Konstante Herzfrequenz: ein neues herzfrequenzbasiertes Verfahren zur Abschaetzung der Ausdauerleistungsgrenze beim Radfahren. / The maximal constant heart rate - a new heart-rate based method for determining the endurance performance limit in cycling. / Frequence cardiaque maximale constante - une nouvelle methode basee sur la frequence cardiaque pour evaluer la limite d'endurance en cyclisme. Leistungssport 2003, 33:4-9.

41. Weekes S, Davie A, Zhou S: Validation of the Dmax method as a predictor of lactate threshold - abstract. In In, Australian Conference of Science and Medicine in Sport,

National Convention Centre, Canberra 28-31 October 1996: abstracts, Bruce, ACT, Sports Medicine Australia, 1996, p 444-445. Australia1996

42. Wyatt FB: Comparison of lactate and ventilatory threshold to maximal oxygen consumption: a meta-analysis. / Comparaison des seuils lactique et ventilatoire a la consommation maximale d ' oxygene: une meta-analyse. Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc) 1999, 13:67-71.

43. Zhou S, Weston SB: Reliability of using the D-max method to define physiological responses to incremental exercise testing. Physiol Meas 1997, 18:145-154.

APPENDIX B

CONSENT FORM

Project Title: **A Field Test for the Estimation of Heart Rate at Lactate Threshold: The 30-minute Cycling Time Trial**

Principal Investigator: Jason Penry, Ph.D.
Student Researcher: Staci Partridge, Aaron Seipel
Co-Investigator(s):
Sponsor: none
Version Date: 1/28/14

---

1. WHAT IS THE PURPOSE OF THIS FORM?

This consent form gives you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

2. WHY IS THIS RESEARCH STUDY BEING DONE?

The purpose of this research study is to investigate the accuracy and reliability of the 30-minute cycling time trial in determining heart rate at lactate threshold. The 30-minute cycling time trial is a widely recommended and used field test to determine the heart rate by which athletes can base their training plans. The utility of this specific field test is in question for all ability levels. The information acquired in this study will help coaches and athletes make an informed decision on whether or not to use this test to base training programs on.

Up to 50 participants may be invited to take part in this study. The investigators intend to publish these findings in a peer-reviewed journal and present these results at a professional conference in the near future. This study will also serve as the masters thesis research for Staci Partridge, one of the student investigators named above.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are an apparently healthy adult with some training or competitive experience with cycling and are between the age of 18 and 45 years old.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

During this study, you will participate in two repetitions of a stationary cycling test, one maximal graded exercise test and one body composition test. Each test day will be followed by at least 24 hours of rest and you will be asked to complete all tests within a four-week period. Your total time commitment is approximately 4 hours.

You are asked to maintain your current activity level and refrain from strenuous activity for the period of 24 hours before each test. In addition, we ask that you refrain from eating for at least 2 hours prior to the test and consume the same meal prior to each test. We will ask you about each of these considerations each time you visit the lab for a testing session.

For each test, you are asked to bring your own bicycle to the lab.

Descriptions of each test follow below:

Maximal graded exercise test. This is an exercise test that progresses from low to high intensity to measure the maximal rate at which your body can use oxygen during physical activity, and the level of lactate in your blood. This test will be conducted on your own bicycle in the Oregon State University Human Performance Laboratory and will require you to cycle for 30-45 minutes on your own bicycle on a stationary trainer. You will wear a mask to collect the air you breathe out during the test. We will draw your blood with a finger stick at rest, at the end of warm up, every 3 minutes during the test and during minutes 1, 3 and 5 of recovery to analyze your blood lactate levels. During this test, the level of difficulty will increase every 3 minutes until you can no longer continue. In some cases, an additional 5-minute stage will be necessary at your maximal effort. The fatigue experienced following this test will be similar to that felt after completing an eight-mile bike race.

Stationary cycling time trial. This test will be conducted on your own bicycle in the Oregon State University Human Performance Laboratory and will require you to cycle for 45 minutes on your own bicycle on a stationary trainer. You will wear a heart rate monitor during this test. You will select your own warm up intensity for 15 minutes. You will then be asked to cycle at a hard effort continuously for 30 minutes. You will be able to adjust the intensity as desired and will be allowed to drink water. After completing the 30-minute trial, you may cool down as you wish.

Body composition test. This test will be conducted in the Oregon State University Human Performance Laboratory and involves measuring your body composition by the displacement of air. In order to get accurate results, you cannot eat or exercise for 2 hours before this test and need to be well hydrated. You are asked to wear tight clothing and will sit very still inside a chamber for one minute at a time while breathing normally. The test from start to finish takes approximately 20 minutes. You will only be in the chamber for 2-3 minutes.

WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

You can expect to experience short-term fatigue when completing the 30-minute time trial and the maximal exercise test. There is also a very remote chance that you may suffer a heart attack during a maximal effort on a bicycle. This is considered a low risk for you, since you are physically active and apparently healthy. In addition, every effort will be made to ensure that the areas in which the tests are conducted are free of obstacles that may cause injury.

The possible risks and/or discomforts associated with the exercise testing in the study include:

- Acute exercise may present a risk of sudden death
- Cardiovascular event (i.e., heart attack or cardiac arrhythmia)
  - Overall risk of cardiac events is about 6 events per 10,000 tests
- Serious injury
- Falling
- Physical discomfort from the test and equipment
- Fatigue
- Muscle aches, cramps, joint pain
- Muscle strain and/or joint injury
- Delayed muscle soreness
- Abnormal blood pressure/heart rate
- Shortness of breath
- Lightheadedness, fainting
- Dizziness
- Nausea

The possible risks and/or discomforts associated with the finger stick blood draws in this study include:

- You may experience pain when the lancet goes into your finger. Other than this momentary pain, the discomfort of a finger stick should be minimal.
- A small amount of bleeding under the skin may produce a bruise (minute hematoma)
- The puncture site may be visible and sore to the touch for a short period of time after the collection.

The possible risks and/or discomforts associated with the body composition measurements in the Bod Pod in this study include:

- You may experience claustrophobia (fear of enclosed spaces) during the measurements that use the Bod Pod. There is a button at your knee while you are inside the Bod Pod that will allow you to open the door of the Bod Pod immediately. A window on the Bod Pod will allow you to see and communicate with the investigator.

- There is no physical danger involved with these measurements. Room air is continuously circulated through the Bod Pod compartment when it is closed. The compartment does not lock and you can exit at any time.

5. WHAT HAPPENS IF I AM INJURED?

Oregon State University has no program to pay for research-related injuries. If you think that you have been injured as a result of being in this study, please contact the researchers immediately via Dr. Jason Penry, Principal Investigator, at 541-737- 3265 or jay.penry@oregonstate.edu.

6. WHAT ARE THE BENEFITS OF THIS STUDY?

We do not know if you will benefit from being in this study. However, you will receive information concerning your maximal aerobic capacity, power and threshold heart rate and power as a result of participating in this study. In addition, you will receive an estimate of your current body composition. Moreover, in the future, other people might benefit from this study, as it will allow coaches, other athletes or researchers to better use the 30-minute time trial test to identify heart rate at lactate threshold for training purposes. This will be particularly useful to individuals who are unable to participate in a laboratory version of this test.

7. WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid for being in this research study, but you will receive information regarding your body fat percentage, VO_{2max} and lactate threshold measurements.

8. WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You **will not** be charged for any tests that are being performed for the purposes of this study. You and/or your insurance provider will be responsible for all other medical care expenses. You will be responsible for travel costs to the study site.

9. WHO IS PAYING FOR THIS STUDY?

The Oregon State University Human Performance Laboratory fund is paying for this research.

10. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you. To help ensure confidentiality, we will use identification code numbers

on data forms instead of your name, and will keep all personal information and study data in a locked filing cabinet. Any digital files that are created will be secured via password protection.

We will make every effort to protect your identity but there is a risk that information, which identifies you, could be accidentally disclosed.

If the results of this project are published, your identity will not be made public.

WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

11. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please email Jason Penry (jay.penry@oregonstate.edu) or Staci Partridge (partrids@onid.orst.edu).

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu.

12. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date: Delete this line only if the study is exempt. The IRB will insert the appropriate date when the consent form is approved.

Participant's Name (printed): _____

_____ _____

(Signature of Participant) (Date)

_____ _____

(Signature of Person Obtaining Consent) (Date)