AN ABSTRACT OF THE THESIS OF

Staci M. Partridge for the degree of Master of Science in Exercise and Sport Science presented on April 15, 2015.

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

Abstract approved:

_____________________________________________________________________
_____________________________________________________________________

Jason T. Penry

The purpose of this study was to examine the validity and reliability of the 30-minute cycling time trial to estimate the heart rate at lactate threshold. Recreationally trained cyclists and triathletes (n = 47) performed 3 tests in random order: 1) One graded exercise test to directly determine lactate threshold (Dmax and 1.5mmol increase methods) 2) Two 30-minute stationary cycling time trials on a bicycle ergometer. The average heart rate and power over the last 20 minutes of the time trial was used to estimate lactate threshold. A subset of participants had respiratory gases measured during the graded test to determine ventilatory threshold and VO$_{2\text{max}}$ (n=31). The heart rate and power during the two time trials were not different. The 30-minute cycling time trial over estimated the heart rate at lactate threshold (1.5mmol mean difference = 6.8 bpm, p < 0.0001; Dmax mean difference = 6.0 bpm, p < 0.001). Power during the last 20 minutes of the time trial did not differ from lactate threshold. In the subset of participants, ventilatory threshold heart rate and power were not significantly different than lactate threshold heart rate or power. These findings
suggest the 30-minute stationary cycling time trial is reliable but should not be used for estimating the heart rate at lactate threshold.
A Field Test for the Estimation of Heart Rate at Lactate Threshold: The 30-minute Cycling Time Trial

by

Staci M. Partridge

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Dean of the Graduate School

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

________________________________________________________________________

Staci M. Partridge, Author
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CONTRIBUTION OF AUTHORS

Dr. Jay Penry was involved in the project design, draft revision for this document and assisted with the analysis and interpretation of the data. Aaron Seipel assisted with data collection.
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<td>30-minute Cycling Time Trial</td>
<td>30CTT</td>
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<tr>
<td>5-kilometer time trial</td>
<td>5ktt</td>
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<td>Analysis of Variance</td>
<td>ANOVA</td>
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<td>Anaerobic Threshold</td>
<td>AT</td>
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<td>Blood Lactate Concentration</td>
<td>BLC</td>
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<td>beats per minute</td>
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<td>The maximum perpendicular distance from the line made from the two end values and the lactate curve</td>
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The point at which blood lactate concentration raises above the lactate minimum by 1.5mmol/L.

Lactate Threshold as determined by the Dmax method $\text{LT}_{Dmax}$

Maximal Constant Heart Rate $\text{MCHR}$

Maximal Lactate Steady State $\text{MLSS}$

Nicotinamide Adenine Dinucleotide $\text{NAD}^+$

Onset of Blood Lactate Accumulation $\text{OBLA}$

Performance Threshold $\text{PT}$

Respiratory Exchange Ratio $\text{RER}$

Rating of Perceived Exertion $\text{RPE}$

Revolutions per minute $\text{RPM}$

Standard deviation $\text{SD}$

Volume of Oxygen Consumption $\text{VO}_2$

Maximal Oxygen Consumption $\text{VO}_{2\text{max}}$

Ventilatory Threshold $\text{VT}$

Wattage or Watts $\text{W}$

Watts per kilogram $\text{W/kg}$

Power /watts at lactate threshold as determined by Dmax $\text{W}_{\text{LT}_{Dmax}}$

Maximal Lactate Steady State Power $\text{W}_{\text{MLSS}}$

Watts at Ventilatory Threshold $\text{W}_{\text{VT}}$
INTRODUCTION

An individual’s metabolic threshold is often suggested as the basis for determining endurance training exercise intensity (27, 30, 36, 37, 44, 48, 55). This metabolic threshold has been defined using several methods, with maximal lactate steady state (MLSS), lactate threshold (LT), and ventilatory threshold (VT) most commonly investigated. The heart rate (HR) or power output found at this metabolic threshold is then used to prescribe training zones for an athlete to optimize training adaptations and improve subsequent performance (1, 33, 34).

MLSS is currently regarded as the gold standard of threshold measurements and represents the maximum workload an individual can sustain without a progressive increase in blood lactate concentration (BLC) (7, 8, 31, 41). Identifying HR and workload at MLSS requires several constant load tests lasting 30 minutes each, during which blood lactate is sampled periodically (41). Due to the demanding and temporal nature of MLSS testing, researchers have attempted to identify the physiological variables associated with MLSS using a single maximal graded exercise test (GXT_max) (7, 24, 26, 28, 41, 68). Of the ways to identify lactate threshold during any given GXT_max two methods have been shown to closely relate to MLSS in cyclists: Dmax for identifying power at MLSS (W_{MLSS}), and an increase in blood lactate of 1.5mmol/L from the minimum BLC for identifying HR at MLSS (HR_{MLSS})(26, 41).

During cycling, both the maximal and sustained power that can be achieved depends on body weight, gender and training status. Individuals with greater body weight
require more power to maintain the same speed as someone with a lower body weight. As such, when comparing power between cyclists, power needs to be expressed in relative terms of wattage (W) per kilogram (kg) (1, 26). In terms of gender, males are generally able to produce more W/kg than females. Likewise, highly trained individuals achieve and are able to maintain higher power outputs than less trained individuals of the same gender and weight. Of the existing protocols for GXTmax using cycling ergometers, most are designed for a homogenous population. In the current study, we designed a protocol for GXTmax tests that can be applied to nonhomogeneous populations. This protocol takes into account body weight, gender and training status, as we tested a wide variety of participants.

Our protocol involves estimating the power at lactate threshold and using that power to determine both the starting power and the incremental increases for the GXTmax. To estimate a participant’s lactate threshold power, we applied concepts from Allen and Coggan (1) who devised a power profile based on gender, weight and training status. This profile includes eight levels of training status from untrained to world class professional and the corresponding functional threshold power (FTP). FTP is the highest power output that can be maintained for one hour (1). As HR demonstrates a linear relationship with power output, (4) FTP as defined by Allen and Coggan (1) is expected to be similar to power at LT. The power profile is shown in table 1, while our protocol is described in the methods section.

While incremental laboratory tests that involve collecting gas or blood variables can be useful in determining training intensities, access to laboratory based incremental
testing is not always available or feasible and is often expensive. Incremental tests require sophisticated equipment and administrators specifically trained in the operation of necessary equipment. A need exists for accurate field tests methods that can be used by a variety of test administrators in a non-laboratory environment (16).

In response to this need, various field-testing methods have been designed to estimate the HR or power output at which LT is reached. In general, there are two categories of field tests, 1) incremental tests of increasing workloads (17), and 2) determination of average heart rate (HR_{avg}) or power over a fixed time interval or distance (54, 66).

Of the currently available field tests, the 30-minute cycling time trial (30CTT) is recommended and used in identifying lactate or ventilatory threshold HR (34). The 30CTT is a maximal exercise bout during which the HR_{avg} over the last 20 minutes approximates HR_{LT} (34). 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 HR_{LT} in well-trained runners (49), the validity of this method for cyclists is unknown.

The main objective of the current study was to therefore to expand the utility of this test to cyclists by identifying the validity and reliability of the 30CTT as a means of estimating the HR_{LT} evaluated by the Dmax (HR_{LT,Dmax}) and 1.5mmol/L lactate increase (HR_{LT,1.5}) methods in a range of competitive experiences. The second
objective was to determine the applicability of 30CTT for estimating the HR_{LT} across a range of competitive abilities as described by W/kg at LT. In a subset of our participants, we also evaluated HR at ventilatory threshold (HR_{VT}) to compare with HR_{30CTT} and HR_{LT}.

To our knowledge, this represents the first investigation comparing the 30CTT method to LT and ventilatory threshold (VT) and the first to compare HR and power at VT to LT_{Dmax} and LT_{1.5} in a broader population.

LITERATURE REVIEW

To maximize endurance and performance, the development and execution of a training plan is critical. A concept which is closely tied to endurance performance and training is that of metabolic threshold, commonly (improperly) referred to as anaerobic threshold (AT) (3). AT is defined as “the highest sustained intensity of exercise for which measurement of oxygen uptake can account for the entire energy requirement” (65). AT is often thought of as a transition where, at a high enough intensity of exercise, the body will change from aerobic metabolism to anaerobic metabolism (29). However, this transition is not related to a simple shift of metabolism from aerobic to anaerobic, but rather represents the point where the rate of glycolysis exceeds the capacity of the mitochondria to utilize pyruvate and regenerate nicotinamide adenine dinucleotide (NAD+). In order to replenish NAD+ and continue glycolysis, lactate is formed (18). At a high enough level of intensity, lactate begins to accumulate. Because aerobic metabolism is accompanied by anaerobic metabolism, and not replaced by it, researchers are adapting other terms
to describe the threshold such as performance threshold (PT) (3), onset of blood lactate accumulation (OBLA) (63) or more commonly LT and MLSS. No matter which threshold parameter is used, all have been demonstrated to be good predictors of performance in cycling and running events, and athletes with higher thresholds demonstrate superior performance to those possessing the same maximal aerobic capacity (VO\textsubscript{2max})(5). Exercise prescription based on thresholds has therefore been widely recommended for many years (36, 37).

MAXIMAL LACTATE STEADY STATE

MLSS is regarded as the gold standard of threshold measures (7, 8, 13, 31, 41) and is defined as the maximum intensity or workload that can be maintained for a 30-minute period without blood lactate accumulation beyond that accrued during the first ten minutes (26). MLSS is achieved when the change in BLC over the last 20 minutes of a constant workload exercise bout is less than 1 mmol/L (41).

The reliability of MLSS was recently investigated by Hauser and colleagues (43). In their study, 32 males from different sports completed four MLSS tests on a cycle ergometer. The power at MLSS showed high reliability (ICC of 0.98, p<0.001) and low day-to-day variability (coefficient of variability (CV) 3%). The BLC at MLSS however was highly variable between participants (CV 16.6%) and had low day-to-day reliability (ICC of 0.71 p<0.001). It was concluded that the power at MLSS is reliable but the comparison of MLSS power should not be directly compared to incremental tests based on a set BLC (42).
The direct determination of workload at MLSS requires several constant load tests lasting at least 30 minutes over the course of multiple days or weeks (7, 8). During the constant load test, BLC is tested several times, usually in 5-10 minute increments. The change in BLC over the last 20 minutes of the test is determined. If the BLC does not change or declines during the initial test, the next test is performed at a higher workload. This is repeated until the increase in BLC is less than 1 mmol/L during the last 20 minutes of the test. If during the initial test the BLC increases, the workload is then decreased for the next test. This is repeated until the change in BLC is less than 1 mmol/L during the last 20 minutes of the test (65).

MLSS testing often requires three to eight sessions of testing in order to determine the exact workload that elicits MLSS in a specific individual. It has been shown that training at and around MLSS improves performance (54), however the process of determining MLSS can have a detrimental effect on training, and can be cumbersome to the athlete. For this reason, MLSS testing is often reserved for research investigations (71).

ONSET OF BLOOD LACTATE ACCUMULATION
For many years, the OBLA has been described as the workload at which BLC is equal to 4.0mmol/L (47). This is because the average BLC at MLSS has long been noted to be 4.0mmol/L (13, 75). However, it has since been suggested by researchers that to determine LT, individualized approaches rather than a fixed BLC should be used. Harnish and colleagues (42) found the average BLC at MLSS in trained cyclists to be
higher than OBLA at 6.7±0.7 mmol/L. More recently, it was demonstrated that during a 30-minute time trial, cyclists were able to maintain an average BLC of 5.3±0.3 mmol/L, with a very wide range between participants (29). Similar findings were observed in a study of 12 triathletes performing cycling exercise, in which the participants maintained an average BLC of 10.6 mmol/L during a 30-minute time trial (54). Finally, as mentioned above, BLC at MLSS is highly variable day-to-day (43). OBLA is still used in research investigations, however it seems alternative definitions to describe LT are being increasingly utilized.

LACTATE THRESHOLD

Lactate threshold is the exercise intensity that is associated with a substantial increase in blood lactate during incremental exercise (16, 46, 65). The term LT is also frequently used in lay literature when designing training zones and prescribing workout intensity (1, 33, 34).

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 tissue recruited, during activity (7). For this reason, athletes should identify LT for each different sporting discipline independently.

Like power, HR also varies with exercise type, however HR<sub>LT</sub> 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<sub>LT</sub> 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 (48).

There are numerous ways to determine LT. In cycling, incremental bicycle ergometer tests are used. Test design will be discussed later in this review. 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, 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 (43, 75).

**Identification of Lactate Threshold.** After incremental testing is performed, a blood lactate curve is plotted. Twenty-five ways to identify the LT were identified in a recent review by Faude and colleagues (31). The 25 concepts of LT identification were categorized into three groups and can be reviewed there (31). 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 at 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 of the blood lactate curve” (31), which includes the ‘Dmax’ method (see below). Of these concepts, the Dmax method has been shown to be both valid and reliable in terms of determining LT and predicting performance.

*Dmax.* In 1992, Cheng and colleagues proposed a model for the determination of VT and LT (24). This model uses a third order curvilinear regression of BLC versus volume of oxygen consumption (VO₂). 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 Dmax, LT could always be detected. In addition, it has good reproducibility and is an objective method (24). Zhou and colleagues found the HR at Dmax to be reliable (ICC of 0.93, p<0.01) (75). Dmax 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) (26). In a study headed by Weekes, cycling at 15W above Dmax resulted in increasing BLC while cycling at or below Dmax workload resulted in a stable BLC (72).
**Lactate Threshold 1.5mmol.** Another method for estimating $HR_{MLSS}$ and $W_{MLSS}$ was proposed originally by Berg in 1990 and further investigated by Grossl et al. in 2012 (12, 41). The method is referred to as anaerobic threshold in these studies but will be referred to as $LT_{1.5}$. During a $GXT_{max}$, $LT_{1.5}$ is described as the workload where BLC raises above the lactate minimum by 1.5mmol/L (41). In other words, after plotting the blood lactate curve, the first point on the curve 1.5mmol/L higher than the lowest point BLC during exercise is $LT_{1.5}$. In trained cyclists, this method was found to have a high correlation with MLSS power ($r=0.95$), and the HR at MLSS was not significantly different than the $HR_{LT_{1.5}}$. This method of determining LT does not require athletes to increase workload to volitional exhaustion and therefore, may be a more desirable method for athletes who test their threshold parameters frequently.

**VENTILATORY THRESHOLD**

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 –VT (6, 73). VT can be determined in the midst of a $VO_{2max}$ test and allows for shorter duration intervals along with shorter total test duration. This can make the determination of VT more palatable to the participant. There is still controversy about whether or not VT is as capable a predictor of performance as LT, and little has been done to investigate the training effects of training plans based on $HR_{VT}$. Even so, a study by Amann et al. (2) showed $HR_{VT}$ or power at VT ($W_{VT}$) to be a better predictor of performance than $HR_{LT}$ or $W_{LT}$. In a meta-analysis comparing VT
to LT, it was concluded that the two measures are not different and therefore VT can be used in place of LT (73).

MAXIMAL OXYGEN CONSUMPTION

In an incremental test to volitional exhaustion where respiratory gases are analyzed, VO$_{2\text{max}}$ can be determined. VO$_{2\text{max}}$ is closely related to performance in endurance events and is used as a way to quantify aerobic capacity. VO$_{2\text{max}}$ 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 (32). In light of the common phenomenon of participants seeming to reach maximal exertion, but failing to reach a plateau in oxygen consumption, secondary variables have been identified to indicate a “true” VO$_{2\text{max}}$ in absence of a plateau. Two commonly used variables are a respiratory exchange ratio (RER) of greater than 1.1 (32), or a maximal HR within ±10 beats of the age-predicted maximum (57). The validity of such variables has been criticized recently in a study that performed verification of VO$_{2\text{max}}$ after the test, in which only 60% of participants achieved a plateau at their maximal workload (57). An RER of ≥1.1 underestimated VO$_{2\text{max}}$ by as much as 27%. Using an RER of ≥1.15 lowered that to 16%. Using a HR of HR$_{\text{max}}$ ±10 beats also underestimates VO$_{2\text{max}}$ and alternatively, excludes those who did reach a true plateau. It was suggested that rather than use secondary variables to verify a maximal test, that researchers perform a verification stage above the maximal workload in the VO$_{2\text{max}}$ test (57). In a follow up study, Meir and others
found similar results when using the verification stage following the VO\textsubscript{2max} test (51). It was concluded that in the absence of a plateau during a VO\textsubscript{2max} test, a verification stage should be used to determine the true VO\textsubscript{2max} rather than using secondary variables such as HR or RER (51, 57).

**INCREMENTAL TEST DESIGN**

Attempting to make comparisons between studies involving LT is often difficult as the methods for incremental or grade cycling-based exercise tests are numerous. In addition, the fitness level of the participants is often very variable. After reviewing the methodology of over 30 studies, only five of the protocols were used in more than one study, with four of them used twice and one used three times. A warm up phase was not always reported or necessarily used. The initial wattage applied ranged between 0 and 200W. The incremental increase in W was typically between 15W and 50W, and was sometimes based on the participant’s mass. Stage durations ranged from 30 seconds to eight minutes and were sometimes variable depending on physiologic responses. Five studies included females; and the remainder studied exclusively males (see table 2). These variations in study protocols emphasize the need to develop a standardized protocol for incremental cycling-based exercise testing.

In addition to workload, the stage duration among tests varies greatly. The effects of manipulating stage duration can be found in a review by Bentley, Newell and Bishop (11). It has been shown that for LT testing, stages need to be at least three minutes
long, and some tests use stage durations up to 10 minutes long (10). $\text{VO}_{2\text{max}}$ tests generally use 1-minute stages and thus it was previously thought that $\text{VO}_{2\text{max}}$ and LT could not be determined from a single test. When comparing 1-minute to 3-minute stages, peak power is lower in the 3-minute stage tests, but $\text{VO}_{2\text{max}}$ and power at LT remain unchanged (10, 60). As such, identification of $\text{VO}_{2\text{max}}$ and LT in a single test is therefore considered possible.

**TRAINING ZONES**

Along with covering miles, athletes are asked to train in HR or power zones based on LT parameters (1, 33, 34). Many training zones have been established over the years, with between three to seven zones based on HR, power, oxygen consumption or BLC (13, 25, 27, 30, 36, 37, 44, 48, 55). The benefits of training in different zones are discussed in detail in Allen and Coggan’s book, *Training and Racing with a Power Meter* (1). Some of the expected physiological/performance adaptations that occur in response to training include increases in plasma volume, muscle mitochondrial enzyme activity, LT, muscle glycogen concentration, 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 $\text{HR}_{\text{LT}}$, which corresponds to a region of between 11-20 beats per minute (bpm) depending on the $\text{HR}_{\text{LT}}$ (1, 33, 34). While training zones based on power and HR are available, the cost of power meters still remains high at $700 to $5000.
HEART RATE DRIFT

During steady state cycling, a phenomenon known as cardiac or heart rate drift often occurs. Researchers have reported a drift or increase in HR of between 4 bpm to 20 bpm over a 30-minute constant load test (21, 26, 37, 40, 44, 53, 64, 69). It had been hypothesized that the main reason for cardiac drift was due to exercise-induced dehydration. To answer this question, 9 male triathletes were studied in 2 sessions, one in an euhydrated state and one in a dehydrated state. The found that $HR_{LT_{D\text{max}}}$ remained stable, but the power/watts at $D_{\text{max}}$ ($W_{LT_{D\text{max}}}$) decreased with dehydration. They concluded that in this case, cardiac drift was not correlated with the degree of dehydration (69). These findings were consistent with similar studies. It was speculated that the cardiac drift observed in both eu- and dehydrated states was due to hyperthermia. As participants experience a redistribution of blood from the central circulation to the cutaneous circulation for cooling, diastolic filling would be reduced, therefore reducing stroke volume and resulting in an increased HR (69). Upon finding similar results, another study suggested that performing steady state exercise outdoors might lessen the effects of heat as the wind caused by cycling velocity may increase convection and cooling (40). Another study reported alternative mechanisms for cardiac drift including an increase in serum catecholamine, hydrogen ion and lactate concentrations (26). Regardless of the underlying mechanisms, heart rate drift has been used to explain the lack of correlation between HR during steady state exercise and $HR_{LT}$ found in incremental exercise tests (21, 26, 40).
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. A need exists for accurate tests that can be used by a variety of test administrators or athletes themselves with little equipment in a non-laboratory environment (16).

In response to this need, various field-testing methods have been designed to estimate the HR or workload 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 (53). 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 (35), incremental test in a velodrome (38), 5-kilometer time trial + 30-minute time trial (42, 66), 40-kilometer time trial (42), maximal constant heart rate test (70, 71), and the 30CTT (34). The last four tests have been specifically identified for their ease of administration and need for very little equipment.

5-kilometer Time Trial. The 5-kilometer time trial (5kTT) followed by a 30-minute constant velocity test as described by Swensen et al. (66) and later validated by Harnish et al. has been shown to provide a valid estimate of the HR_{MLSS} in male and female competitive cyclists (42). Athletes first complete a 5kTT at maximal effort.
Then, they perform a 30-minute trial at 90-92% of the average speed from the 5kTT. The average HR during the MLSS test was 167±9.5 BPM and the average HR during the 30-minute test was 165±9.9 BPM and was not significantly different (66).

**40-kilometer Time Trial.** In the above-mentioned study, Harnish also included a 40-kilometer time trial for comparison and found the HR_{MLSS} was nearly identical to the 30-minute trial (174.7 ± 2.6BPM vs 174.1 ± 2.1 BPM respectively) (42).

**Maximal Constant Heart Rate.** Vobejda and colleagues (70, 71) have validated the maximal constant HR (MCHR) method in both cyclists and runners. For this test, cyclists start at a HR of 170BPM and maintain that HR regardless of power for 30 minutes. If they can successfully maintain that HR they repeat the trial at 10 bpm higher until they can no longer maintain the selected HR. After failing to complete a trial, the next 30-minute test is at 5 bpm lower than the previous test. If the athlete is able to maintain the lower HR, the HR_{MLSS} is identified. If in the initial 30-minute trial, they are unable to maintain the HR of 170 BPM, the next and successive trials are performed at 10 bpm lower until they can maintain the HR. The last trial is 5 bpm higher than the first sustainable HR. While this test is simple, the number of trials is much higher than other methods and the authors do not recommend this method for beginning or minimally-trained individuals (71).

**30-minute Time Trial.** The 30CTT is frequently recommended and used (34, 54) for identifying HR_{LT} by taking the HR_{avg} over the last 20 minutes of a maximal steady
state exercise bout. The advantage of this model is the simplicity of the protocol and the convenience of 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$_{LT}$ by OBLA in runners (49), the HR$_{LTD_{max}}$ was significantly lower than the time trial HR. Additionally; the validity of this test in cycling is unknown. In a study on the transferability of HR between running and cycling, the authors found HR$_{LT}$ was up to 20 bpm lower during cycling than running. The average intra-subject difference was 6.4 BPM (95%CI 5.4-7.3 bpm) and the authors concluded that transferability between cycling and running is uncertain (59). A later study regarding the transferability of running and cycling training zones in triathletes identified no statistical difference between HR in cycling versus running, however the error was 12 bpm, which was considered too high for practical use (21).

Groslambert and colleagues compared the physiological variables that are commonly monitored in the 30-minute time trial to the individual AT method and VT. This study found that HR$_{avg}$ was a poor estimator of threshold HR due to cardiac drift. During this study, HR was averaged over the entire 30 minutes instead of the last 20 minutes (40) which led to the conclusion that the 30CTT method may overestimate HR$_{LT}$. In addition, the investigators did not identify HR$_{LTD_{max}}$ or HR$_{LT1.5}$, which have since been shown to be good estimators of HR$_{MLSS}$ (26, 41).

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 (71) while others such as the 30CTT used by Friel (34) are
recommended for all levels of experience. 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. However, their study used a fixed BLC of 3.5mmol/L to identify lactate threshold (28).

This information coupled with the specificity of LT to the muscle groups used and the type of exercise (7) indicates the need to validate the 30CTT, which is a popular field testing method. If this method is shown to be accurate, it will allow athletes to estimate HR\text{LT} with a single test and a commercially available HR monitor.

MATERIALS AND METHODS

PARTICIPANTS

Twenty-two cyclists and 28 triathletes with a variety of competitive experience volunteered for this study (n = 31 males, n = 19 females). Three male participants (2 triathletes and 1 cyclist) did not complete the required testing within the four-week time window and as such, were not included in our analysis. All participants had experience in training for cycling events and most had racing experience (<1 year of racing n = 14; 1-4 years of racing n= 13; ≥5 years of racing n = 18; 2 no response). Individuals of all fitness levels were encouraged to participate in the study. All participants were aged between 18 and 43 years (mean age = 26.1±7) and did not possess more than 1 risk factor for cardiovascular disease. Descriptive characteristics for all test participants are presented in table 3. A subset of
participants (n = 31) had ventilatory data collected during the lactate threshold test to determine VT and VO\textsubscript{2max}. Participant consent for this study was obtained via a written informed consent form. The Oregon State University Institutional Review Board (IRB) approved this form along with all procedures and recruitment materials.

PROCEDURES

All testing was completed in the Oregon State University Human Performance Laboratory. All participants completed two trials of the 30CTT and one trial of the GXT\textsubscript{max} in a random order. During the first visit, all participants also completed preliminary screening and a body composition test. Each participant completed all three tests within a four-week (28 day) window, although most participants completed testing within a much shorter period of time (mean = 15 ± 7 days). This four-week window was chosen to minimize any changes in VO\textsubscript{2max} associated with a training effect. It has been shown that minimal training effect occurs in a six-week period of intense training (3-4% improvement in VO\textsubscript{2max}) (22). Because participants were asked to maintain their current activity level and complete all testing in a short time frame, little change in true VO\textsubscript{2max} was expected. All testing was performed between the hours of 6am and 12pm to minimize diurnal variations in HR (23). Participants were asked to refrain from any exercise in the 24 hours before testing and to eat a similar evening meal and the same breakfast before each test. Meal and exercise compliance were verified by self-report. Participants were verbally
encouraged to give a maximal effort during each test and were blinded to all data during the test with the exception of time and cadence. The results of the GXT\textsubscript{max} and the time trials were given to the participants upon completion of all three tests.

MEASURES

*Instruments.* Body composition was found using the Bod Pod (Cosmed USA, Concord, CA). To assess gas exchange, a ParvoMedics TrueMax 2400 metabolic cart (ParvoMedics, Sandy, UT), was used. Heart rate was monitored using a Polar HR monitor (Polar, Lake Success, NY) for the GXT\textsubscript{max} and a Garmin Edge 500 (Garmin International, Olathe, KS) for the time trials. Participants brought their own bicycles to the lab to ride on the CompuTrainer for the testing. Tire pressure was standardized at 100psi. Bicycles were set up on a CompuTrainer (test-retest reliability of ±1%) (RacerMate, Seattle, WA) for all tests. Blood lactate concentrations were assessed during the GXT\textsubscript{max} using a Lactate Pro Analyzer (Cycle Classic Imports, Carlton, NSW, Australia). All instruments were calibrated before each testing session using standards provided by the manufacturer.

*Maximal Graded Exercise Test.* For this test, resting blood lactate was collected prior to the warm up stage. Participants then completed a 10-minute self-selected warm up before calibration of the CompuTrainer. After calibration, 31 of the participants were fitted with a mouthpiece and nose clip before stage 1 for the collection of expired gases throughout the test.

The starting power and incremental increases were selected based on the Coggan
power profile (table 1) (1). An estimate for lactate threshold was made based on estimated FTP for each participant’s gender, training status and weight. Stage increases were 8% of the estimated threshold power rounded to the nearest 5W with a range of 10-25W (mean = 18.8 ± 4.4). Starting power was set at four stages lower than estimated threshold power and ranged from 50-250W (mean = 153.8 ± 48.1). Constant load stage duration was 3 minutes. During the last 30 seconds of each stage, capillary blood was collected via finger-stick from a clean dry fingertip and immediately analyzed. Rating of perceived exertion (RPE) by the Borg scale of 6-20 was also collected at that time (15). Fingertip blood samples were also collected and analyzed during recovery (1, 3 and 5 minutes) to determine blood lactate concentration.

Cadence was self-selected between 70 and 100 revolutions per minute (RPM). Digital RPM and time were displayed for the participant to view. The participant was asked to maintain the selected cadence for the duration of the test. If cadence fell below 70 RPM, participants were encouraged to increase their cadence back above 70 within 10 seconds. If participants were unable to increase cadence above 70, if cadence fell below 70 RPM more than twice, or the participant indicated that he/she could not continue, the test was ended. Cool down was at a self-selected cadence with minimal resistance and continued until BLC began decreasing which marked the last blood sample. Participants then chose when to stop.

*Identification of Maximal Aerobic Power.* $\text{VO}_2\text{max}$ was determined as the highest $\text{VO}_2$ uptake over a one-minute average during the last stage of the GXT$_{\text{max}}$. $\text{VO}_2\text{max}$ was
achieved if there was a plateau in oxygen consumption evidenced by an oxygen uptake difference of less than 2.1 mL/kg/min between the final minute average and the last minute average from the previous stage (32, 57). If a plateau was not achieved, the participants then performed a verification stage (51) as follows. After a 10-minute cool down at minimal resistance, the power was gradually increased over a 2-minute period until the final power of the GXT max was reached. After 1 minute, the power was increased to one stage higher than the maximal power achieved in the GXT max. The participants were encouraged to continue for at least 2 minutes. The VO2 plateau was determined by comparing the final minute of the GXT max and the final minute of the verification stage. In the event that a plateau was not demonstrated, a second verification stage was performed at two stages higher than the maximal wattage achieved in the GXT max. RER and maximal HR were not used as indicators of a maximal effort due to the extended duration of the test and due to underestimation of VO2max by the traditional methods (51).

Identification of Lactate Threshold. In the literature, there are several ways to determine LT and thereby HRLT. Each method is based on defining either the inflection point in the blood-lactate curve, a set BLC or a specific rise in BLC from baseline (31). Two methods were to be used in this study, Dmax (LT Dmax) (24, 26) and an increase of 1.5mmol/L increase above the lactate minimum (LT1.5) (41). The Dmax method was chosen for its objectivity and reliability. BLC, W and HR were recorded in excel and uploaded to the Lactate-OR software application available online through rstudio (52). Dmax was hand-calculated for participants whose BLC data exhibited a sigmoidal (S-shaped) curve, which precluded the use of Lactate-OR
The LT$_{1.5}$ was selected for its validity in estimating the HR$_{MLSS}$ and W$_{MLSS}$ in cyclists. LT$_{1.5}$ was identified using the same software used to find Dmax. In addition, VT was identified by the V-slope method based on 30-second ventilatory averages (6) using the provided TrueOne Metabolic Cart software.

**Time Trial:** The 30-minute stationary cycling time trial method as described by Friel was used (34). Each participant was fitted with a Garmin HR monitor to collect data. Only test time and cadence were displayed for the participant. Participants were free to adjust power and cadence at any time throughout the warm up and test but were blinded to that power and the increase amount. After a 15-minute warm up, the CompuTrainer was calibrated. Participants then began a 30-minute all out time trial effort. Participants were instructed to provide a maximal, consistent effort for the duration of the 30CTT. Participants were fan cooled by 2 fans and were allowed to drink water ad libitum. The HR and power were averaged each minute throughout the 30CTT. The HR$_{avg}$ during the last 20 minutes (HR$_{30CTT}$) was compared to the threshold HRs found in the GXT$_{max}$ and between time trials.

**Body Composition:** On the first visit to the laboratory, each participant had a body composition test performed using the Bod Pod (Cosmed USA, Concord, CA). The Bod Pod was warmed up and calibrated according to the manufacturers recommendations. Participants dressed down to tight fitting clothing. Height and weight were measured using a standard stadiometer and the calibrated Bod Pod scale respectively. Body composition was calculated based on the Siri calculation.
STATISTICAL ANALYSES

For all statistical procedures, IBM SPSS Statistics (IBM, Armonk, NY) and Excel (Microsoft, Redmond, WA) were used.

Descriptive Statistics. Mean and standard deviation (SD) were calculated for all demographic data (age, height, weight, body fat, racing experience, relative VO₂max and power at threshold) and for GXTₘₐₓ power (starting power, incremental increases).

Power. A power calculation was performed to determine the number of participants required to achieve a power of 0.8 and an alpha error of 0.05. To detect a difference of 6bpm or more with a standard deviation 12bpm, 47 participants were required. Analysis of genders individually would greatly reduce power or detectable difference.

Validity and Reliability. A one-way repeated measures analysis of variance (ANOVA) was used to compare HR and W/kg during the 30CTT1, 30CTT2, LTₐₜₜₜ, and LT₁.₅. A second, one-way repeated measures ANOVA compared HR and W/kg during the 30CTT1, 30CTT2, VT, LTₐₜₜₜ and LT₁.₅ in the participant subset with ventilatory data. Comparison of means between genders was not run due to limitations of sample size.

Agreement. To assess agreement between the time trials, Bland-Altman plots were used (14). After checking for normality of the data, HR differences for the two 30CTT Ts were plotted on the Y-axis, whereas the mean values for the 2 trials were
plotted on the X-axis. To assess agreement between the threshold HRs and the HR from the first 30CTT, a Bland-Altman plot was also used. SPSS (IBM, Armonk, NY) was used to plot the mean difference between test scores and the average of the test scores.

*Practice Application.* To assess the practical application of the 30CTT across a range of cycling experience, the individual difference between the \( \text{HR}_{30\text{CTT}} \) and the \( \text{HR}_{\text{LT}1.5} \) was plotted against years of racing experience, minutes of bicycle specific training each week and and W/kg at LT_{1.5}.

**30CTT HR & W/kg Trends.** 30CTT one-minute average HR data was plotted against time to examine the data for cardiac drift. A similar methodology was used for W/kg over the duration of the test to examine pacing strategy. The relationship between these variables was examined by dividing HR by W/kg and plotting this coefficient over the duration of the 30CTT. Cardiac drift was determined using the coefficient from the second minute of the test. The first minute was not used, as participants used the first minute to increase power from the warm up. The HR for the same coefficient at minute 30 was calculated using the ending power. The difference between the final HR and the calculated HR represents cardiac drift, or an increase in HR that cannot be explained by a subsequent increase in power.

*Post-hoc analysis of HR_{30CTT}.* A paired t-test was used to compare the means of the HR_{avg} over the entire 30CTT to the HR_{LT1.5}.
RESULTS

Reliability of 30CTT. The HR\text{avg} and the average power over the last 20 minutes of the 30CTT were not significantly different between time trials in the combined group. The time trial results (mean ± SD) are presented in table 4. A Bland-Altman plot was used to assess agreement between the two tests. There appears to be good agreement across a range of HR and power (figure 1).

Validity of 30CTT HR. Comparison of 30CTT1 to threshold measures is presented in table 5. The HR\text{30CTT1} was significantly higher than both HR\text{LT1.5} and HR\text{LTDmax} (mean = 6.83 bpm, p<0.0001; mean = 6.00 bpm, p<0.001). The HR\text{avg} for 30 minutes was also significantly different (p<0.01) from HR\text{LT1.5} but showed a smaller mean difference (3.45 bpm) than the 20-minute HR\text{avg}. No significant difference was found between HR\text{30CTT1} and HR\text{VT} in the VT subset (p > 0.05). Bland-Altman plots were used to assess agreement between the HR\text{30CTT} and the HR\text{LT} (figure 2) or HR\text{VT} (figure 3). Lower HR values showed an increased distribution of HR differences, reflecting lower agreement at these values.

Validity of 30CTT Power. No significant difference was found between the 30CTT power and the power at LT\text{Dmax}, LT\text{1.5} or VT. Bland-Altman plots were used to assess agreement between the 30CTT power and the power at LT\text{1.5}, LT\text{Dmax}, or VT (figure 4). Females appeared to have time trial power results closer to Dmax across the range of power. All males except two had higher time trial power results than Dmax power. At higher power values, the mean difference from threshold increased with
the 30CTT power being greater than power at \( LT_{D\text{max}} \) and \( LT_{1.5} \) (figure 4). The mean difference in power between 30CTT and VT appears to decrease as power increases (figure 5).

*Validity by Training Status.* The mean difference between \( HR_{30CTT} \) and \( HR_{LT1.5} \) was the same across training status as described by minutes of bicycle specific training per week, years of racing experience, or power at \( LT_{1.5} \) (figure 6). At 3 W/kg and higher, all females had higher power in the time trial than the mean. At just over 240 minutes of cycling per week, all women had 30CTT HRs 10 bpm or higher than \( HR_{LT1.5} \). As a group, there was good agreement across training status.

*\( LT \) vs \( VT \).* No significant difference was found between \( HR_{VT} \) when compared to \( HR_{LT1.5} \) or \( HR_{LTD\text{max}} \) (\( p > 0.05 \), table 5). Power at VT was not significantly different from power at \( LT_{1.5} \) or \( LT_{D\text{max}} \). Agreement was examined via Bland-Altman plots. At higher HRs, \( HR_{VT} \) was greater than both \( HR_{LT_{D\text{max}}} \) and \( HR_{LT1.5} \) while at lower HRs, \( HR_{LT_{D\text{max}}} \) and \( HR_{LT1.5} \) were greater than \( HR_{VT} \) (figure 7). While there was no significant difference in power between LT and VT, the Bland-Altman plot revealed that at higher powers, power at VT was greater than at LT while at lower powers, power at LT was greater than power at VT (figure 8).

*Pacing and Cardiac Drift.* On average, both HR and power output increased during the 30CTTs. In the first 30CTT, HR showed steady increase from minute 5 to minute 30. From minute 2 to minute 30, HR increased from 156 bpm to 177 bpm. Power
started at 2.98 W/kg, had a slight decrease over minutes 5 to 20, and then had a marked increase over the last 10 minutes with the last 5 minutes having the steepest increase to 3.3 W/kg at the end of the test. Power increased by 0.11 W/kg from minute 20 to 25 and by 0.23 W/kg from minute 25 to 30.

In the second 30CTT, HR has a similar increase over the course of the test from minute 2 to 30 (155bpm to 177bpm). There was no decrease in average power during the second 30CTT. There was a steady increase from minute 2 (2.8W/kg) to 25 (3.04W/kg) followed by a marked increase over the last 5 minutes with the last minute having the steepest increase. The final power output was the same between both 30CTT at 3.3W/kg.

When comparing the increase in HR to the increase in power during 30CTT1, HR increased more than power over the first 15 minutes of the test, and then power increased more than heart rate over the last 15 minutes of the test. Overall, HR increased more than power over the duration of the test. When comparing the increase in HR to the increase in power during 30CTT2, HR increases more than power over the first 5 minutes of the test. HR and power increases remain relatively constant over minutes 5-25. Power then increases more than heart rate during the last 5 minutes of the test. Overall, HR increases more than power over the duration of the test. Cardiac drift was estimated to be 4bpm in 30CTT1, while no cardiac drift was apparent in 30CTT2.
DISCUSSION

The main findings of this study were that the 30CTT (as described by Friel, 34), overestimates HR_{LT} by approximately 7 bpm across training levels. These findings were similar to those of McGehee et al when they compared the 30-minute time trial (30RTT) to LT in endurance trained runners and triathletes. In their study, HR_{LT_{TD_{max}}} was significantly lower than the HR in the 30RTT (49). To our knowledge, the McGehee study is the only study to investigate the 30-minute time trial method. While the 30CTT over estimates HR_{LT}, this test does accurately predict the power at LT. Upon further investigation of the 30CTT HRs, it appears that the 30-minute HR_{avg} rather than the 20-minute average may estimate the LT_{HR} more accurately. While significantly different than HR_{LT_{1.5}}, the HR_{avg} over 30 minutes was had a smaller mean difference (3.45 bpm) than the 20 minute HR_{avg} (6.83 bpm). It should be noted that during the first few minutes of the time trial effort, HR was not at steady state for many participants as they increased their efforts from the warm up levels. This could introduce error in the time trial investigations and should be considered when testing.

Regardless of training, most cyclists and triathletes in our study achieved an HR_{avg} greater than their lactate threshold while cycling for 30 minutes. This would suggest that a longer exercise bout might be needed to estimate HR_{LT}. Harnish and colleagues have shown evidence that a test lasting approximately 60 minutes (40k TT with experienced cyclists) provides a HR_{avg} that is equal to HR_{MLSS} (42).
Participants used two different pacing strategies even though the same instructions for a constant effort were given each time. In the first 30CTT, they started off quickly, slowed, and then increased speed again over the last 10 minutes. In the second effort, they continuously added resistance throughout the test with further increases in the last 5 minutes. This would suggest that they were better able to gauge their effort on the second time trial; however, the HR$_{avg}$ and average power were not different. This also suggests that pacing during a sustained effort improves with practice.

During steady state cycling, a phenomenon known as cardiac or heart rate drift often occurs. Researchers have reported a drift or increase in HR of 4 to 20 BPM over a 30-minute constant load test (21, 26, 37, 40, 44, 54, 64, 69). It had been hypothesized that the main reason for cardiac drift was due to exercise-induced dehydration. To answer this question, 9 male triathletes were studied in two sessions, one in a euhydrated state and one in a dehydrated state. It was found that HR$_{LTD_{max}}$ remained stable, but the W$_{LTD_{max}}$ decreased with dehydration. Therefore it was concluded that in this case, heart rate drift was not correlated with degree of dehydration. It was speculated that the cardiac drift observed in both eu- and dehydrated states was due to hyperthermia. As participants experience a redistribution of blood from the central circulation to the cutaneous circulation for cooling, diastolic filling would be reduced, therefore reducing stroke volume and resulting in an increased HR (69). Upon finding similar results, another study suggested that performing steady state exercise outdoors might lessen the effects of
heat as the wind caused by cycling velocity may increase convection and cooling (40). Regardless of the underlying mechanisms, cardiac drift has been used to explain the lack of correlation between HR during steady state exercise and HR\textsubscript{LT} found in incremental exercise tests (21, 26, 40). Our participants were tested in an air-conditioned room and were cooled with 2 fans during the 30CTT and GXT\textsubscript{max}. The average temperature of the laboratory was 21.3°C (70.3°F). The first 30CTT had approximately 4bpm of cardiac drift and the second 30CTT did not appear to have cardiac drift. This does not account for the total difference between the HR\textsubscript{30CTT} and HR\textsubscript{LT}, but future research should investigate the validity of the 30CTT outdoors as suggested by Gros lambert et al. (40).

The 30CTT protocol investigated was specific to stationary indoor cycling, not outdoor cycling. Due to the lack of previous research on the day-to-day reliability of the 30CTT, as well as the possible variability of climate and other factors, we chose not to investigate the outdoor version of this test during this study. As power during the 30CTT was found to be reflective of power at lactate threshold, future investigations should test the validity of this protocol when performed in an external environment.

The age range selected for this study was comprised of young adults to middle aged adults. This population was 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.
PRACTICAL APPLICATION

The 30CTT is already widely accepted as a method to determine $HR_{LT}$ in cyclists. The results of this study provide empirical evidence on which practitioners can base their recommendations. Previous investigations of field tests have assessed the validity of various field methods on homogenous populations of trained athletes (35, 38, 42, 66, 70, 71). In our study, we expanded the population of interest to all levels of recreationally trained athletes. Practitioners now have evidence that this method overestimates $HR_{LT}$ in novice to advanced athletes, but provides accurate power data. When prescribing training plans based on $HR_{LT}$, our recommendation is when using the 30CTT, to use the $HR_{avg}$ over the entire duration of the 30-minute test rather than the last 20 minutes. Alternatively, other field-testing methods may be used such as the 5kTT followed by a 30-minute constant velocity test as described by Swensen et al. (66) and later validated by Harnish et al (42). This method has been shown to provide a valid estimate of the $HR_{MLSS}$ (42) and only requires one additional test session. Athletes first complete a 5kTT at maximal effort. Then, they perform a 30-minute trial at 90-92% of the average speed from the 5kTT. The average HR during the MLSS test ($167\pm9.5$ bpm) and the average HR during the 30-minute test ($165\pm9.9$ bpm) were not significantly different (66). Based on previous research, a 60-minute time trial may provide a closer estimation of $HR_{LT}$, but further research is needed to support this claim (42).
We found lactate threshold testing with a non-homogenous population is more challenging than with a group of trained athletes. The blood lactate curve is not always exponential at the end of GXT\textsubscript{max}, which can make calculation of Dmax more difficult. In addition, it is important for athletes to work to exhaustion. We found that if peak BLC results from a stage that was only partially completed, the resultant BLC curve is almost always sigmoidal as the lactate response for that workload is incomplete compared to previously completed stages. Because HR\textsubscript{LTDmax}, HR\textsubscript{LT1.5}, and HR\textsubscript{VT} were not significantly different, the ease of the LT\textsubscript{1.5} protocol, the need for fewer BLC test strips, and the option for termination of the graded test before maximal exertion, the use of LT\textsubscript{1.5} is recommended for general use.
Table 1. Functional Threshold Power

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<th>Women</th>
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<table>
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<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg men</td>
<td>5.51</td>
<td>4.87</td>
</tr>
<tr>
<td>avg women</td>
<td>5.42</td>
<td>4.79</td>
</tr>
<tr>
<td>FTP</td>
<td>5.51</td>
<td>4.87</td>
</tr>
<tr>
<td>avg men</td>
<td>5.42</td>
<td>4.79</td>
</tr>
<tr>
<td>avg women</td>
<td>5.33</td>
<td>4.70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Excellent (e.g., cat. 1)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg men</td>
<td>4.98</td>
<td>4.38</td>
</tr>
<tr>
<td>avg women</td>
<td>4.89</td>
<td>4.29</td>
</tr>
<tr>
<td>FTP</td>
<td>4.98</td>
<td>4.38</td>
</tr>
<tr>
<td>avg men</td>
<td>4.89</td>
<td>4.29</td>
</tr>
<tr>
<td>avg women</td>
<td>4.80</td>
<td>4.21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Very good (e.g., cat. 2)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg men</td>
<td>4.44</td>
<td>3.88</td>
</tr>
<tr>
<td>avg women</td>
<td>4.35</td>
<td>3.80</td>
</tr>
<tr>
<td>FTP</td>
<td>4.44</td>
<td>3.88</td>
</tr>
<tr>
<td>avg men</td>
<td>4.35</td>
<td>3.80</td>
</tr>
<tr>
<td>avg women</td>
<td>4.27</td>
<td>3.72</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Good (e.g., cat. 3)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg men</td>
<td>3.87</td>
<td>3.31</td>
</tr>
<tr>
<td>avg women</td>
<td>3.73</td>
<td>3.23</td>
</tr>
<tr>
<td>FTP</td>
<td>3.87</td>
<td>3.31</td>
</tr>
<tr>
<td>avg men</td>
<td>3.73</td>
<td>3.23</td>
</tr>
<tr>
<td>avg women</td>
<td>3.64</td>
<td>3.14</td>
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</table>

<table>
<thead>
<tr>
<th>Moderate (e.g., cat. 4)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg men</td>
<td>3.29</td>
<td>2.82</td>
</tr>
<tr>
<td>avg women</td>
<td>3.20</td>
<td>2.73</td>
</tr>
<tr>
<td>FTP</td>
<td>3.29</td>
<td>2.82</td>
</tr>
<tr>
<td>avg men</td>
<td>3.20</td>
<td>2.73</td>
</tr>
<tr>
<td>avg women</td>
<td>3.11</td>
<td>2.65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fair (e.g., cat. 5)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg men</td>
<td>2.75</td>
<td>2.24</td>
</tr>
<tr>
<td>avg women</td>
<td>2.66</td>
<td>2.24</td>
</tr>
<tr>
<td>FTP</td>
<td>2.75</td>
<td>2.24</td>
</tr>
<tr>
<td>avg men</td>
<td>2.66</td>
<td>2.24</td>
</tr>
<tr>
<td>avg women</td>
<td>2.58</td>
<td>2.16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Untrained (e.g., non-racer)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg men</td>
<td>2.18</td>
<td>1.67</td>
</tr>
<tr>
<td>avg women</td>
<td>2.04</td>
<td>1.58</td>
</tr>
<tr>
<td>FTP</td>
<td>2.13</td>
<td>1.75</td>
</tr>
<tr>
<td>avg men</td>
<td>2.13</td>
<td>1.75</td>
</tr>
<tr>
<td>avg women</td>
<td>1.95</td>
<td>1.58</td>
</tr>
</tbody>
</table>

avg men: average for men
avg women: average for women
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Test</th>
<th>Warm Up Duration (min)</th>
<th>W Warm Up</th>
<th>W Initial</th>
<th>W Increase</th>
<th>Stage Duration (min)</th>
<th>Cadence</th>
<th>gender</th>
<th>Participant/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arumugam (2)</td>
<td>2006</td>
<td>LT</td>
<td>30</td>
<td>15 W/kg</td>
<td>100</td>
<td>50</td>
<td>5</td>
<td>not reported</td>
<td>M</td>
<td>well-trained cyclists</td>
</tr>
<tr>
<td>Bentley (8)</td>
<td>2003</td>
<td>LT</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>not reported</td>
<td>M</td>
<td>endurance athletes (triathlon, cycling or rowing), 8 recreational athletes</td>
</tr>
<tr>
<td>Bentley (9)</td>
<td>2001</td>
<td>LT</td>
<td>10</td>
<td>15</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>not reported</td>
<td>M</td>
<td>competitive TT triathletes</td>
</tr>
<tr>
<td>Bentley (10)</td>
<td>2003</td>
<td>LT</td>
<td>5</td>
<td>15</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>not reported</td>
<td>M</td>
<td>triathletes</td>
</tr>
<tr>
<td>Bisogno (17)</td>
<td>2004</td>
<td>LT</td>
<td>15</td>
<td>5 min/6 sec</td>
<td>150</td>
<td>40</td>
<td>3</td>
<td>subjects</td>
<td>M</td>
<td>mud cyclists</td>
</tr>
<tr>
<td>Brown (19)</td>
<td>2008</td>
<td>LT/60%max</td>
<td>100</td>
<td>120-150</td>
<td>20 h</td>
<td>5 subjects</td>
<td>div 23</td>
<td>subjects</td>
<td>M</td>
<td>endurance trained cyclists</td>
</tr>
<tr>
<td>Cadorani (28)</td>
<td>2008</td>
<td>LT</td>
<td>3</td>
<td>0</td>
<td>25</td>
<td>25</td>
<td>3</td>
<td>&lt;80</td>
<td>M</td>
<td>recreational cyclists 2-3 times/week</td>
</tr>
<tr>
<td>Cheng (24)</td>
<td>1992</td>
<td>LT</td>
<td>5</td>
<td>100</td>
<td>100</td>
<td>50</td>
<td>5</td>
<td>75-90</td>
<td>M</td>
<td>cyclists, 2 years min competitive experience</td>
</tr>
<tr>
<td>Crane (females/130)</td>
<td>2009</td>
<td>LT</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>30</td>
<td>3</td>
<td>not reported</td>
<td>F</td>
<td>well-trained cyclists</td>
</tr>
<tr>
<td>Crane (males/26)</td>
<td>2009</td>
<td>LT</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>40</td>
<td>3</td>
<td>not reported</td>
<td>M</td>
<td>well-trained cyclists</td>
</tr>
<tr>
<td>Donadio (trained/20)</td>
<td>2004</td>
<td>LT</td>
<td>0</td>
<td>0</td>
<td>105</td>
<td>35</td>
<td>3</td>
<td>70</td>
<td>M</td>
<td>endurance cyclists</td>
</tr>
<tr>
<td>Donadio (untrained/20)</td>
<td>2005</td>
<td>LT</td>
<td>0</td>
<td>0</td>
<td>70</td>
<td>35</td>
<td>3</td>
<td>70</td>
<td>M</td>
<td>untrained</td>
</tr>
<tr>
<td>Donadio (20)</td>
<td>2006</td>
<td>LT/60%max</td>
<td>0</td>
<td>0</td>
<td>200</td>
<td>30</td>
<td>3</td>
<td>not reported</td>
<td>M</td>
<td>trained cyclists with TT experience</td>
</tr>
<tr>
<td>Dostal (9)</td>
<td>2012</td>
<td>LT</td>
<td>0</td>
<td>0</td>
<td>150</td>
<td>25</td>
<td>3</td>
<td>not reported</td>
<td>M</td>
<td>trained cyclists</td>
</tr>
<tr>
<td>Gennaro (females/130)</td>
<td>2007</td>
<td>LT/60%max</td>
<td>1.0</td>
<td>100</td>
<td>130</td>
<td>30</td>
<td>4</td>
<td>38</td>
<td>F</td>
<td>trained cyclists and triathletes with VO2 &gt; 50 and 2 years more experience</td>
</tr>
<tr>
<td>Gennaro (male/130)</td>
<td>2007</td>
<td>LT/60%max</td>
<td>1.0</td>
<td>100</td>
<td>200</td>
<td>30</td>
<td>4</td>
<td>48</td>
<td>M</td>
<td>trained cyclist and triathletes with VO2 &gt; 50 and 2 years more experience</td>
</tr>
<tr>
<td>Greco (trained/99)</td>
<td>2012</td>
<td>LT</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>35</td>
<td>3</td>
<td>70</td>
<td>M</td>
<td>trained endurance cyclists</td>
</tr>
<tr>
<td>Grond (41)</td>
<td>2012</td>
<td>LT</td>
<td>0</td>
<td>0</td>
<td>105</td>
<td>35</td>
<td>3</td>
<td>not reported</td>
<td>M</td>
<td>trained cyclists</td>
</tr>
</tbody>
</table>
| Harper (65)            | 2007 | LT/VT  | 0                      | 0         | 25        | 25         | 3                    | 50          | M       | range of aerobic capacities                                                            | 276 ± 63.1 ± 0.4 F
| McNaughton (90)        | 2006 | LT     | 5                      | 100       | 150-200   | 25         | 3                    | not reported | M      | mod-well trained cyclists                                                               | 62.8 ± 0.8 |
| McNaughton (90)        | 2006 | LT     | 5                      | 100       | 150-200   | 25         | 5                    | not reported | M      | mod-well trained cyclists                                                               | 62.8 ± 0.8 |
| Plano (females/16)     | 2009 | LT     | "self-selected"        | 10 W/kg   | 0         | 25        | 3                    | not reported | M      | trained cyclists                                                                       | 489 ± 24 |
| Plano (males/56)       | 2009 | LT     | "self-selected"        | 20-25 W/kg| 0         | 25        | 3                    | not reported | M      | trained cyclists                                                                       | 599 ± 38 |
| Rechichi (58)          | 2007 | LT/60%max | 0             | 0         | 50        | 25         | 3                    | not reported | M      | trained cyclists                                                                       | 590 ± 36 |
| Rosegay (trained/61)   | 2006 | LT     | 0                      | 0         | 90        | 30         | 3                    | >80         | M      | competitive/open race runners or cyclists                                             | not measured |
| Rosegay (untrained/61) | 2006 | LT     | 0                      | 0         | 30        | 30         | 3                    | >80         | M      | competitive/open race runners or cyclists                                             | not measured |
| Schneider (trained/3)  | 1992 | LT/60%max | 3             | 0         | 0         | 25        | 3                    | not reported | M      | well-trained cyclists                                                                  | 4.83 ± 1.3 |
| Takiunome (7)          | 2016 | LT     | 2                      | 0         | 15        | 25        | 2                    | 60          | M      | elite runners (trained n=72, untrained n=172)                                        | 3.86 ± 2.75, 26.1 ± 7.9
| Van Schoorbenbroek (60) | 2004 | LT/60%max | 20             | 100       | 50        | 5          | 5                    | subjects     | M      | elite cyclists                                                                          | 5.48 ± 0.26 |
| Van Schoorbenbroek (60) | 2004 | LT/60%max | 20             | 100       | 60        | 6          | 6                    | subjects     | M      | elite cyclists                                                                          | 5.48 ± 0.26 |
| Van Schoorbenbroek (60) | 2005 | LT     | 200                   | 100       | 50        | 5          | 30                   | subjects     | M      | triathletes who competed at national level in Olympic and Ironman distance triathlons  | 6.59 ± 2.7 |
| Wosneski (72)          | 1996 | LT     | 0                      | 0         | 50        | 10         | 3                    | not reported | M      | endurance cyclists 1 year earlier                                                   | 6.52 ± 0.52 |
| Wyatt (76)             | 2005 | YST/VO2max | 0             | 50        | 50        | 5          | 2                    | not reported | M      | Cat. 5 cyclists                                                                         | 56.2 ± 1.2 |
| Zhou (75)              | 1997 | LT/60%max | 10             | 15        | 10        | 15         | 3                    | cycles and triathletes                                                                 | 4.62 ± 0.377 |

**Footnotes:**

1. 1.5 minutes at 50% VO2max then 15 s at 1.5 W/kg.
2. *When a lactate value greater than 4.5 mmol/L was achieved, exercise intensity was reduced and subjects were given a 10 minute recovery at a power output approximately 50 W below the cyclic rate at which a lactate of approximately 4.5 mmol/L was achieved.*
3. Subject often performed an incremental test to determine maximal oxygen consumption (VO2max), starting at a power output equivalent to that achieved at a lactate of approximately 4.5 mmol/L, during which power output was increased by 20 Watts/min.
4. **until End**, 6 min until End then 2 min until exhaustion.
### Table 3. Descriptive Characteristics of Participants

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Body Fat (%)</th>
<th>Racing Experience (y)</th>
<th>Cycling/Week (min)</th>
<th>Relative VO2max*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined</td>
<td>47</td>
<td>26.1 ± 7.0</td>
<td>175.4 ± 9.3</td>
<td>70.6 ± 6.9</td>
<td>18.9 ± 7.4</td>
<td>4.2 ± 4.5</td>
<td>287 ± 201</td>
<td></td>
</tr>
<tr>
<td>VT subset</td>
<td>31</td>
<td>24.3 ± 6.0</td>
<td>175.7 ± 9.6</td>
<td>70.1 ± 8.1</td>
<td>19.3 ± 8.1</td>
<td>4.4 ± 4.1</td>
<td>283 ± 216</td>
<td>50.4 ± 9.0</td>
</tr>
<tr>
<td>Males</td>
<td>28</td>
<td>26.8 ± 7.5</td>
<td>181.5 ± 4.7</td>
<td>74.9 ± 5.8</td>
<td>14.6 ± 5.1</td>
<td>5.1 ± 4.8</td>
<td>314 ± 204</td>
<td></td>
</tr>
<tr>
<td>VT subset</td>
<td>18</td>
<td>24.7 ± 6.4</td>
<td>182.2 ± 5.0</td>
<td>75.0 ± 5.0</td>
<td>14.0 ± 5.1</td>
<td>4.6 ± 3.6</td>
<td>312 ± 223</td>
<td>56.4 ± 5.6</td>
</tr>
<tr>
<td>Females</td>
<td>19</td>
<td>25.2 ± 6.3</td>
<td>166.4 ± 6.8</td>
<td>61.9 ± 6.9</td>
<td>25.4 ± 5.2</td>
<td>3.0 ± 3.8</td>
<td>247 ± 194</td>
<td></td>
</tr>
<tr>
<td>VT subset</td>
<td>13</td>
<td>23.8 ± 5.7</td>
<td>166.6 ± 6.5</td>
<td>63.2 ± 6.3</td>
<td>26.6 ± 5.3</td>
<td>2.4 ± 3.4</td>
<td>244 ± 206</td>
<td>42.1 ± 5.5</td>
</tr>
</tbody>
</table>

* Ventilatory data was collected for 31 participants (18 males, 13 females)

### Table 4. Comparison of Time Trial 1 to Time Trial 2

<table>
<thead>
<tr>
<th></th>
<th>TT1</th>
<th>TT2</th>
<th>TT1</th>
<th>TT2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HR avg 20</strong></td>
<td>171.66 ± 11.56</td>
<td>170.36 ± 11.61</td>
<td>167.59 ± 10.58</td>
<td>167.46 ± 10.99</td>
</tr>
<tr>
<td><strong>HR avg 30</strong></td>
<td>167.88 ± 12.35</td>
<td>164.43 ± 12.42</td>
<td>163.88 ± 11.21</td>
<td>167.35 ± 12.68</td>
</tr>
<tr>
<td>W/kg avg 20**</td>
<td>3.01 ± 0.64</td>
<td>3.02 ± 0.65</td>
<td>3.27 ± 0.56</td>
<td>3.26 ± 0.57</td>
</tr>
<tr>
<td>Cadence</td>
<td>95.57 ± 8.11</td>
<td>94.47 ± 8.11</td>
<td>96.82 ± 11.47</td>
<td>95.68 ± 6.71</td>
</tr>
<tr>
<td>RPE**</td>
<td>15.81 ± 1.24</td>
<td>15.73 ± 1.16</td>
<td>15.94 ± 1.09</td>
<td>15.86 ± 1.06</td>
</tr>
</tbody>
</table>

*Average HR over last 20 minutes of the 30CTT
**Average HR over the entire 30CTT
*Average workload over last 20 minutes of the 30CTT
^^Rating of Perceived Exertion on the Borg Scale 6-20

### Table 5. Comparison of Heart Rate and Power during Time Trial 1 to Threshold Measures

#### Heart Rate (bpm)

<table>
<thead>
<tr>
<th></th>
<th>TT1</th>
<th>LTDmax</th>
<th>LT1.5</th>
<th>VT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined</td>
<td>171.66 ± 11.56&lt;sup&gt;b&lt;/sup&gt;</td>
<td>165.70 ± 11.71&lt;sup&gt;b&lt;/sup&gt;</td>
<td>164.83 ± 11.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>VT subset</td>
<td>172.55 ± 9.84&lt;sup&gt;c&lt;/sup&gt;</td>
<td>167.32 ± 11.28&lt;sup&gt;d&lt;/sup&gt;</td>
<td>165.87 ± 10.30&lt;sup&gt;d&lt;/sup&gt;</td>
<td>167.84 ± 13.93</td>
</tr>
<tr>
<td>Males</td>
<td>167.59 ± 10.58</td>
<td>161.68 ± 10.63</td>
<td>160.43 ± 10.10</td>
<td></td>
</tr>
<tr>
<td>VT subset</td>
<td>170.59 ± 9.64</td>
<td>164.67 ± 11.08</td>
<td>162.28 ± 9.86</td>
<td>164.11 ± 13.65</td>
</tr>
<tr>
<td>Females</td>
<td>177.39 ± 10.90</td>
<td>171.63 ± 10.88</td>
<td>171.32 ± 9.89</td>
<td></td>
</tr>
<tr>
<td>VT subset</td>
<td>175.16 ± 9.97</td>
<td>171.00 ± 10.91</td>
<td>170.85 ± 9.03</td>
<td>173.00 ± 13.10</td>
</tr>
</tbody>
</table>

#### Power (W/kg)

<table>
<thead>
<tr>
<th></th>
<th>TT1</th>
<th>LTDmax</th>
<th>LT1.5</th>
<th>VT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined</td>
<td>3.01 ± 0.64</td>
<td>2.96 ± 0.66</td>
<td>2.92 ± 0.61</td>
<td></td>
</tr>
<tr>
<td>VT subset</td>
<td>2.94 ± 0.69</td>
<td>2.96 ± 0.72</td>
<td>2.87 ± 0.62</td>
<td>3.02 ± 0.73</td>
</tr>
<tr>
<td>Males</td>
<td>3.27 ± 0.56</td>
<td>3.29 ± 0.51</td>
<td>3.20 ± 0.52</td>
<td></td>
</tr>
<tr>
<td>VT subset</td>
<td>3.28 ± 0.63</td>
<td>3.37 ± 0.56</td>
<td>3.19 ± 0.55</td>
<td>3.34 ± 0.69</td>
</tr>
<tr>
<td>Females</td>
<td>2.63 ± 0.55</td>
<td>2.47 ± 0.55</td>
<td>2.49 ± 0.49</td>
<td></td>
</tr>
<tr>
<td>VT subset</td>
<td>2.47 ± 0.47</td>
<td>2.39 ± 0.51</td>
<td>2.41 ± 0.42</td>
<td>2.58 ± 0.53</td>
</tr>
</tbody>
</table>

<sup>a</sup> Significantly different p<0.0001
<sup>b</sup> Significantly different p<0.001
<sup>c</sup> Significantly different p<0.005
<sup>d</sup> Significantly different p<0.05
**Figure 1.** Bland-Altman plots for the HR and power during the 30CTT1 vs. 30CTT2. The solid line represents the average difference from the mean, while the dashed lines mark the edge of the 95% confidence interval. Note the relatively consistent distribution of HR differences across the range of HRs and power.

**Figure 2.** Bland-Altman plots for the HR\text{30CTT1} vs. HR\text{LT1.5} and HR\text{LTDMAX} measures. The solid line represents the average difference from the mean, while the dashed lines mark the edge of the 95% confidence interval. Note the increased distribution of HR differences at lower HRs.
**Figure 3.** Bland-Altman plot for the HR_{30CTT} vs. HR_{VT}. The solid line represents the average difference from the mean, while the dashed lines mark the edge of the 95% confidence interval. Note at lower HR, 30CTT HR is greater while at higher HR, HR_{VT} is greater.

**Figure 4.** Bland-Altman plots for the 30CTT1 power vs. LT power. The solid line represents the average difference from the mean, while the dashed lines mark the edge of the 95% confidence interval. Note the females have a smaller mean difference than the males. Males appear to have a greater difference between 30CTT and LT at higher powers with the 30CTT power being greater than power at LT.
Figure 5. Bland-Altman plot for the 30CTT1 power vs. VT power. The solid line represents the average difference from the mean, while the dashed lines mark the edge of the 95% confidence interval. Note the increased distribution of power differences at lower powers. Also note the higher power in males.
Figure 6. Graph of difference in HR between the criterion and field test based on training status. Note the relatively consistent distribution of differences in HR. It appears most participants had a HR_{30CTT} that was above LT regardless of strength, years of racing experience or minutes of cycling specific training each week.
**Figure 7.** Bland-Altman plots for the HR_{VT} vs. HR_{LT,1.5} and HR_{LT,Dmax}. The solid line represents the average difference from the mean, while the dashed lines mark the edge of the 95% confidence interval. Note at higher HRs, HR_{VT} is greater than HR_{LT} while at lower HRs, HR_{LT} is greater than HR_{VT}.

**Figure 8.** Bland-Altman plots for the VT power vs. LT_{1.5} power and LT_{Dmax} power. The solid line represents the average difference from the mean, while the dashed lines mark the edge of the 95% confidence interval. Note at higher powers, power at VT is greater than at LT while at lower powers, power at LT is greater than power at VT.
Figure 9. Graph of average pacing and HR over the course of the 30CTT1 for all participants. Both HR and power increase over the course of the 30-minute test. HR has a steady increase from minute 5 to minute 30 while power has a slight decrease followed by a marked increase over the last 10 minutes with the last 5 minutes having the steepest increase.

Figure 10. Graph of the coefficient of HR and power over the course of the 30CTT1. HR increases more than power over the first 15 minutes of the test and then power increases more than heart rate over the last 15 minutes of the test. Overall, HR increases more than power over the duration of the test.
Figure 11. Graph of average pacing and HR over the course of the 30CTT2 for all participants. Both HR and power increase over the course of the 30-minute test. HR has a steady increase from minute 2 to minute 30. Power has a steady increase from minute 2 to 25 followed by a marked increase over the last 5 minutes with the last minute having the steepest increase.

Figure 12. Graph of the coefficient of HR and power over the course of the 30CTT2. HR increases more than power over the first 5 minutes of the test. HR and power increases remain relatively constant over minutes 5-25. Power then increases more than heart rate during the last 5 minutes of the test. Overall, HR increases more than power over the duration of the test.
REFERENCES


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$_{2}$max tests, as well as actively participated in many such tests himself. His research experience includes work specific to VO$_{2}$max 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$_{2}$MAX 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$_{2}$max 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 addressed, should they arise. He will also be responsible for ensuring the study team 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 VO\textsubscript{2max} testing and administration of questionnaires. Dr. Penry will work closely with S. Partridge and A. Seipel to assure VO\textsubscript{2max} testing equipment is functioning properly. Dr. Penry will oversee VO\textsubscript{2max} assessments. Study team members are already trained on VO\textsubscript{2max} assessments. Dr. Penry has been doing VO\textsubscript{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 at 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 in a 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 reliable 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$_{2\text{max}}$.

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$_{\text{max}}$) 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 counterparts. 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\textsuperscript{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\textsubscript{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\textsubscript{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\textsubscript{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 predetermined 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$_{2\text{max}}$ 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$_{2\text{max}}$)
In an incremental test to volitional exhaustion where respiratory gases are analyzed, VO$_{2\text{max}}$ can be determined. VO$_{2\text{max}}$ is closely related to performance in endurance events and is used as a way to quantify aerobic capacity. VO$_{2\text{max}}$ 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$_{2\text{max}}$ 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$_{2\text{max}}$ after the test (36). In the study, only 60% of participants achieved a plateau at their maximal workload. An RER of >1.1 underestimated VO$_{2\text{max}}$ by as much as 27%. Using an RER of >1.15 lowered that to 16%. Using a HR of HR$_{\text{max}}$ ±10 beats also underestimates VO$_{2\text{max}}$ 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$_{2\text{max}}$ test (36). In a more recent study, Meir and others found similar results when using the verification stage following the VO$_{2\text{max}}$ test (33). It was concluded that in an absence of a plateau during a VO$_{2\text{max}}$ test, that a verification stage should be used to determine the true VO$_{2\text{max}}$ 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$_{\text{LT}}$ (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 CO₂ and O₂ 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 (BPM) 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, VO₂max will be assessed. VO₂max is achieved if there is a VO₂ 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 VO₂ 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 VO₂max test will be provided to the participants upon completion or withdrawal 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 workload for 15 minutes. This warm up will include the calibration stage as in the maximal graded exercise test. 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 ventilatory 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 withdrawal 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\textsubscript{2max} values to examine how consistently 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 stored 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\textsubscript{2}max 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 participant 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.


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 individuals 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


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


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$_{2\text{max}}$ 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)
APPENDIX D

PROPOSAL DOCUMENT

The Reliability of a Maximal Graded Exercise Test to Determine Heart Rate at Lactate Threshold, Ventilatory Threshold and Maximal Oxygen Uptake &

The Validity and Accuracy of the 30-minute Stationary Cycling Time Trial to Predict Heart Rate at Lactate Threshold

Staci Partridge
Oregon State University
January 13, 2014

Major Professor: Jay Penry, PhD
ABSTRACT

To maximize endurance and performance, the development and execution of a training plan is critical. A concept which is closely tied to endurance performance and training is that of lactate threshold (LT) and ventilatory threshold (VT). To determine the heart rate at LT and VT, a maximal graded exercise test (GXT\textsubscript{max}) is performed in the lab although no standardize protocol for such tests exist. The first purpose of this study is to test the reliability of a GXT\textsubscript{max} methodology based on body mass and training status in the determination of HR\textsubscript{LT}, HR\textsubscript{VT} and VO\textsubscript{2}\textsubscript{max}. For those endurance-trained athletes who do not have access to a performance lab, the 30-minute cycling time trial (30CTT) is commonly used as the first step in determining heart rate zones for training; however, the validity of this test is unknown. The second purpose of this study is to examine the 30CTT as a means of identifying the heart rate at lactate threshold (HR\textsubscript{LT}) for all fitness levels. Thirty participants will perform a maximal graded test on a stationary bicycle to measures blood lactate and HR\textsubscript{LT} and VO\textsubscript{2}\textsubscript{max}. The participants will then perform a 30CTT. The relationship of the heart rate average from the last 20 minutes of this time trial to the HR\textsubscript{LT} will be identified using linear regression. The standard error of estimate will be used to assess the accuracy of the test. To examine the accuracy across fitness levels, the error between the two tests will be compared to the respective VO\textsubscript{2}\textsubscript{max} scores.

INTRODUCTION

Blood lactate level during a maximal graded exercise test (GXT\textsubscript{max}) is a measure
commonly used to evaluate the effects of training, to set training intensities, and to maximize and predict performance (14). The highest workload one can sustain without excess lactate accumulation is known as lactate threshold (LT) (14, 45, 63). Accumulated data suggest that exercise intensities derived from the LT may provide the best indices by which to prescribe guidelines for training (11, 14, 23, 25, 28, 34, 35, 42, 46, 52). After determining the heart rate (HR) or power at which LT is reached, coaches will provide HR or power training zones for an athlete to train in to maximize training adaptations and improve performance (1, 31, 32).


Access to such resources is not always available or feasible and is often expensive. These techniques require sophisticated equipment and test administrators
specifically trained in the operation of this equipment. A need also exists for accurate tests that can be used by a variety of test administrators in a non-laboratory environment (Bourdon, 2000).

In response to this need, various field-testing methods have been designed to estimate the heart rate or power at which lactate threshold is reached. In general, there are two categories of field tests, (1) incremental tests of increasing speeds (Bourgois et al, 2004) (2) average heart rate (HRavg) or power over a fixed time interval or distance (Perrey et al., 2002; Swensen et al., 1999). The 30CTT is in the later category.

The 30CTT is widely recommended and used (Friel, 2006, Friel 2010, Perrey et al., 2003) for identifying HRLT by taking the HRavg over the last 20 minutes of a maximal steady state exercise bout. The advantage to using this model is the simplicity of the protocol and the need for a single testing session to determine the heart rate parameters by which an athlete will train. Although this method has been shown to be valid in determining the HRLT in runners (McGehee et al., 2005), the criterion validity in cycling is unknown.

PROBLEM STATEMENT

There are two main objectives of this project. The first is to determine the reliability of a new GXTmax based on body mass and training status to estimate the HRLT, HRVT and VO2max. The second objective is to identify the concurrent validity of the 30CTT as a means of estimating the HRLT. The HRavg during the last 20 minutes of the 30CTT will be compared to HRLT as determined in the standard laboratory test. The
applicability of 30CTT for estimating the HR_{LT} will be compared across a range of competitive abilities as described by HR_{LT}.

Our *central hypothesis* is that the GXT_{max} will be a reliable tool for estimation of HR_{LT} and HR_{VT} and VO_{2max}. For the second part of our study, we expect the 30CTT will result in HR_{avg} that is not significantly different than the HR_{LT} and there will be an agreement across the range of HR_{LT}.

*Specific Aims And Hypotheses:* The present research activity will address three specific aims:

**Aim #1. Establish the reliability of the GXT_{max} in determining HR_{LT} HR_{VT} and VO_{2max}**.

Our hypothesis is that the GXT_{max} will be a reliable measure of HR_{LT} HR_{VT} and VO_{2max}.

**Aim #2. Establish the validity of the 30CTT in predicting heart rate at lactate threshold.**

Our hypothesis is that the HR_{avg} during the last 20 minutes of the 30CTT will accurately identify the HR_{LT} when compared to the laboratory test.

**Aim #3. Assess the accuracy of the 30-minute time trial across competitive levels.**

Our hypothesis is that method of identifying the HR_{LT} by the 30CTT will be accurate across all competitive abilities.
ASSUMPTIONS

Participants will give maximal effort during all tests. Participants will be able to complete maximal testing. Participants will follow the general guidelines provided to them prior to testing.

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 in the ability of untrained cyclists to maintain at a constant workload during the 30CTT. While they may not be experienced in pacing the variations in HR will be addressed by taking the \( \text{HR}_{\text{avg}} \) over the course of the test.

DELIMITATIONS

This protocol will be specific to stationary indoor cycling, not outdoor. Due to the possible variability of climate and other variables, 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 and compare the \( \text{HR}_{\text{LT}} \) found indoors versus outdoors.

The age range selected for this study includes young adults, however this method is used for all ages. This range was chosen for safety reasons and to minimize the
cardiovascular risk factors in our participants. Future studies should examine the validity 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. It was decided that a HR difference of 5 bpm would be meaningful to practitioners. To detect a smaller variation in HR, a much larger sample size should be used.

SIGNIFICANCE
The 30CTT is already widely accepted as a method to determine HR_{LT}. The results of this study will provide empirical evidence on which practitioners can base their recommendations. If found to be a valid and accurate test, the need for invasive laboratory tests to accurately determine training zones will 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. If the method is shown to be valid across fitness levels, practitioners will also have evidence to support the use of this method with beginning to advanced athletes. Should the method be invalid, the cycling community will need to determine a different method for estimating HR_{LT}.

LITERATURE REVIEW
To maximize endurance and performance, the development and execution of a training plan is critical. A concept which is closely tied to endurance performance
and training is that of a metabolic threshold, commonly (improperly) referred to as anaerobic threshold (AT) (Amann 2004). AT is defined as “the highest sustained intensity of exercise for which measurement of oxygen uptake can account for the entire energy requirement” (Svedahl and MacIntosh 2003). AT is often thought of as a transition where at a high enough intensity of exercise, the body will change from aerobic metabolism to anaerobic metabolism (Dumke 2006). However, this transition in not related to a simple shift of metabolism from aerobic to anaerobic, but rather represents the point where the rate of glycolysis exceeds the capacity of the mitochondria to utilize pyruvate and regenerate nicotinamide adenine dinucleotide (NAD). In order to replenish NAD and continue glycolysis, lactic acid is formed (Brooks). At a high enough level of intensity, lactic acid begins to accumulate. Because aerobic metabolism is accompanied by anaerobic metabolism, and not replaced by it, researchers are adapting other terms to describe the threshold such as performance threshold (PT) (Amann 2004), onset of blood lactate accumulation (OBLA) (Sjodin and Jacobs 1981) or more commonly lactate threshold (LT) and maximal lactate steady state (MLSS). No matter which threshold parameter is used, they have all been shown to be good predictors of performance in cycling and running events, and athletes with higher thresholds demonstrate superior performance than those of the same VO$_{2\text{max}}$ (Atkinson, 2003). Exercise prescription based on thresholds has been recommended for many years (Gibbons 1987, Gilman 1996).

MAXIMAL LACTATE STEADY STATE
MLSS is regarded as the gold standard of threshold measures (Beneke, 2003, Billat et al 2003, Faude 2009, Grossl et al 2012) and is defined as the maximum intensity or workload that can be maintained for a 30-minute period without continued blood lactate accumulation (Czuba, 2009). In the lab, this is achieved when the change in blood lactate concentration over the last 20 minutes of the constant intensity exercise bout is less than 1 mmol/L (Grossl 2012).

The reliability of MLSS was recently investigated by Hauser, Bartsch, Baumgärtel and Schulz (2012). In their study, 32 males from different sports completed 4 MLSS tests. The power at MLSS showed high reliability (ICC of 0.98 p<0.001) and low day-to-day variability (coefficient of variability (CV) 3%). The BLC at MLSS however was highly variable between subjects (CV 16.6%) and had low day-to-day reliability (ICC of 0.71 p<0.001) (Hauser et al 2012). It was concluded that the power at MLSS is reliable but the comparison of MLSS power should not be directly compared to incremental tests based on a set BLC.

The direct determination of the MLSS intensity requires several constant load tests lasting at least 30 minutes over the course of multiple days or weeks (Beneke 2003). During the constant load test, BLC is tested several times, usually at 5-10 minute increments. The change in BLC over the last 20 minutes of the test is determined. If the BLC does not change or goes down during the initial test, the next test is performed at a higher intensity. This is repeated until the increase in BLC is less than 1 mmol/L during the last 20 minutes of the test. If during the initial test the
BLC increases, the intensity is then decreased for the next test. This is repeated until the change in BLC is less than 1 mmol/L during the last 20 minutes of the test (Swensen, 1999). MLSS testing often requires 3-8 sessions of testing in order to determine the exact workload that elicits MLSS. It has been shown that training at and around MLSS improves performance (Philp 2007), but the process of testing MLSS can have a detrimental effect on training, and can be cumbersome to the athlete. For this reason, MLSS testing is often reserved for research purposes (Vobejda, 2003).

ONSET OF BLOOD LACTATE ACCUMULATION

For many years, the OBLA has been said to occur at the workload when BLC is equal to 4.0mmol/L (Kindermann, 1979, Sjodin and Jacobs 1981). This is because the average blood lactate concentration at MLSS has long been noted to be 4.0mmol/L (Zhou 1997, Billat 2003). However, it has since been suggested by researchers that to determine LT, individualized approaches rather than a fixed BLC be used. Harnish and colleagues (2001) found the average BLC at MLSS to be higher than OBLA at 6.7+/−0.7 mmol/L. More recently, Dumke (2006) headed a study that found during a 30-minute time trial, the cyclists were able to maintain an average BLC 5.3+/−0.3 mmol/L and it had a very wide range between participants. This was also shown by in a study with 12 triathletes. The participants maintained an average BLC of 10.6mmol/L during a 30-minute time trial (Perrey et al., 2002). Lastly, as mentioned above, BLC at MLSS is highly variable day-to-day (Hauser 2012). OBLA is still used
in research, but it seems more researchers are using alternative definitions to describe the lactate threshold.

**LACTATE THRESHOLD**

Lactate threshold is the exercise intensity that is associated with a substantial increase in blood lactate during incremental exercise (Karlsson and Jacobs, Svedahl and Macintosh, 2002, Bourdon, 2000). The term LT is also frequently used in lay literature when designing training zones and prescribing workout intensity (Friel, 2006, Coggan 2006).

The heart rate and power at lactate threshold differ based on the type of exercise. It has been shown that the amount of lactate produced is specific to type of exercise and is based on amount of muscle used during activity (Beneke 2002). For that reason, athletes should identify his or her lactate threshold for each sport independently.

While the HR varies based on the mode of exercise, the HR\textsubscript{LT} remains stable over the course of a training season. In a study by Lucía and others (2000), professional cyclists were tested for HRLT four times over the course of a year. During the year there were 4 different levels of training ranging from no training to competition. They found that over all levels of training, the HR\textsubscript{LT} remained stable. The concluded that one LT test per season should suffice in trained athletes (Lucía et al 2000).
There are numerous ways to determine LT. In cycling, incremental bicycle ergometer tests are used. Test design will be discussed later in this review. In general, the test begins with a warm up followed by incremental increase at a set time interval. During each stage a blood sample is taken and the BLC is recorded. After the subject reaches volitional exhaustion, the test is terminated and the BLC is plotted against intensity. The intensity at LT is usually defined by power (W), heart rate (HR) or both. Because blood lactate concentrations 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 set BLC (Hauser 2012, Zhou).

Identification of Lactate Threshold. After incremental test, a blood lactate curve is plotted. Twenty-five ways to identify the lactate threshold were identified in a recent review (Faude et al 2009). Faude and colleagues categorized those 25 concepts into 3 groups and can be reviewed there. Briefly, the first category includes all the methods identifying LT based on a fixed BLC of 2-4mmol/L. As we have seen, BLC varies day-to-day, but the concept of LT occurring at OBLA or 4.0mmol/L is still being used. The second category includes LT concepts that identify the first rise in BLC above baseline levels. These concepts have evolved over the years originally being identified visually and later being identified by a specific increase such as 1.0mmol/L greater than baseline. The third category includes LT identified by a “rapid/distinct change in inclination the blood lactate curve” (Faude et al 2009). Of
these concepts, the D-max method has been shown to be both valid and reliable in terms of LT and predicting performance.

*D-max.* In 1992, Cheng and colleagues proposed a model for the determination of ventilatory and lactate thresholds. This model uses a third order curvilinear regression of BLC vs VO2. 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. The intensity can then be identified. The authors concluded that by using D-max, LT can always be detected. In addition, it has good reproducibility and is an objective method (Cheng et al 1992). Zhou and colleagues found the HR at D-max to be reliable (ICC of 0.93, p<0.01) (1997). 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) (Czuba et al 2009). 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 (Weekes 1996). In contrast, when the incremental protocol includes stage durations of 6 minutes, it was shown that HRLT 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**

In addition to BLC related threshold, another threshold based on ventilatory parameters exists and is becoming more widely used due to the noninvasive
methodology – ventilatory threshold (VT) (Beaver 1986, Wyatt 1999). VT can be determined in the midst of a VO₂max test and requires shorter duration intervals along with shorter test duration. This can make the determination of VT more pleasant for the participant. There is still controversy about whether or not this parameter is as predictive of performance, and little has been done to investigate the training effect of a training plan based on HRVT. Even so, some studies have shown HRVT or WVT to be a better predictor of performance than HRLT or WLT (Amann 2006). This study did not compare HRVT to HRLT 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 (Wyatt 1999).

VO₂MAX

In an incremental test to volitional exhaustion where respiratory gases are analyzed, VO₂max can be found. VO₂max is closely related to performance in endurance events and is used as a way to quantify aerobic capacity. VO₂max is achieved when a participant reaches a plateau in VO₂ despite increasing workloads. A plateau is defined as an increase of less than 2.1 mL/kg of oxygen from the previous stage (Franklin, 2000). In light of participants seeming to reach a maximal exertion, but failing to reach a plateau in oxygen consumption, secondary parameters have been identified to indicate a “true” VO₂max in absence of a plateau. Two commonly used parameters are a respiratory exchange ratio (RER) of greater than 1.1 (Franklin, 2000), or a maximal heart rate within ±10 beats of the age-predicted maximum (Poole et al., 2007). The validity of such parameters has been criticized recently in a
study that performed a verification of VO$_{2\text{max}}$ after the test (Poole et al 2007). In the study, only 60% of participants achieved a plateau at their maximal workload. An RER of $\geq 1.1$ underestimated VO$_{2\text{max}}$ by as much as 27%. Using an RER of $\geq 1.15$ lowered that to 16%. Using a HR of HR$_{\text{max}} \pm 10$ beats also underestimates VO$_{2\text{max}}$ and alternatively, excludes those who did reach a true plateau. It was suggested that rather than use secondary parameters to verify a max test, that researchers perform a verification stage above the maximal workload in the VO$_{2\text{max}}$ test (Poole 2007). In a follow up study, Meir and others found similar results when using the verification stage following the VO$_{2\text{max}}$ test (Meir et al 2012). It was concluded that in an absence of a plateau during a VO$_{2\text{max}}$ test, that a verification stage should be used to determine the true VO$_{2\text{max}}$ rather than using secondary parameters such as HR or RER (Poole 2007, Meir et al 2012).

INCREMENTAL TEST DESIGN

Attempting to make comparisons between studies involving LT is often difficult as the methods for incremental or graded exercise tests are numerous. In addition, the fitness level of the subjects is widely varied. After review the methodology of 34 studies, only 5 of the protocols were used in more than once study, 4 of them were used twice and 1 was used 3 times. The warm up phase is not always reported or used. The initial wattage is anywhere between 0 and 200W. The incremental increase is between 15 and 50 and is sometimes based on the subjects’ mass. The stage duration ranges from 30 seconds to 8 minutes and is sometimes variable.
depending on physiologic responses. 5 studies included females; all the others were exclusively male. See table 1. The need for a standardized protocol exists.

In addition at workload, the stage duration among tests varies greatly. The effects of manipulating stage duration can be found in a review by Bentley, Newell and Bishop (2007). It has been shown that for LT testing, stages need to be at least 3 minutes long while some tests use stage durations up to 10 minutes long (Bentley 2003). VO$_{2\text{max}}$ test generally use 1-minute stages and so it was previously thought that VO$_{2\text{max}}$ and LT could not be determined from one test. When comparing 1-minute to 3-minute stages, peak power is lower in the 3-minute stage tests, but VO$_{2\text{max}}$ and power at LT remain unchanged (Roffey 2006, Bentley 2003). As such, identification of VO$_{2\text{max}}$ and LT in a single test is possible.

TRAINING ZONES

In addition to covering miles, athletes are asked to train in heart rate (HR) or power zones based on lactate threshold parameters (Allen & Coggan 2006, Friel, 2006). Many training zones have been established over the years, from 3-7 zones based on heart rate, power, oxygen consumption or blood lactate concentration (Billat 2004, Coen 1991, Dalleck 2010, Faria 2005, Gibbons 1987, Gilman 1996, Jeukendrup 1998, Lucia 2009 Philp 2008). 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 are increased: 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 (Allen and Coggan 2006). The LT zone is from about 95-105% of your HR_{LT} with a range of 11-20 beats per minute (BPM) depending on the HR_{LT} (Allen and Coggan 2006, Friel 2006, Friel 2010). While training zones based on power and heart rate are available, the cost of power meters still remains high at $700 to $5000.

HEART RATE DRIFT

During steady state cycling, a phenomenon know as heart rate drift often occurs. Researchers have reported a drift of 4-20 BPM over a 30-minute constant load test (Carey 2009, Czuba 2009, Snyder 1994, Gilman 1996, Grosolambert 2004, Perrey 2002, Van Schuylenbergh 2005, Jeunkendrup 1998). It had been hypothesized that the main reason for cardiac drift was due to exercise-induced dehydration. To answer this question, 9 male triathletes were recruited to take part in a study involving dehydration. The athletes completed 2 sessions, one in a euhydrated state and one in a dehydrated state. The found that HR at D-max remained stable, but the power at D-max decreased with dehydration. The concluded that in this case, heart rate drift was correlated with the degree of dehydration which was also consistent with similar studies. They speculated the cardiac drift observed in both eu- and dehydrated states was due to hypothermia. As subjects experience a redistribution of blood from the central circulation to cutaneous circulation for cooling, myocardial
filling would be reduced and therefore reducing stroke volume resulting in an increased HR (Van Schuylenbergh 2005). Upon finding similar results of cardiac drift, another study suggested that performing steady state exercise outdoors might lessen the effects of heat as the wind caused by cycling velocity may increase convection and cooling (Groslambert 2004). Another study reported alternative mechanisms for cardiac drift such as an increase in catecholamine levels, hydrogen ion and lactate concentration (Czuba 2009). Regardless of the mechanism, heart rate drift has been used to explain the lack of correlation between the HR during steady state exercise and the HRTL found in incremental exercise tests (Carey 2009, Czuba 2009, Groslambert 2004).

FIELD TESTING

Laboratory testing techniques require sophisticated equipment and test administrators specifically trained in the operation of this 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, is often expensive, and a need exists for accurate tests that can be used by a variety of test administrators or athletes themselves with little equipment in a non-laboratory environment (Bourdon 2000).

In response to this need, various field-testing methods have been designed to estimate the heart rate or power at which lactate threshold 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. 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 (Gavin 2012), incremental test in a velodrome (Gonzalez-Haro 2007), 5-kilometer time trial + 30-minute time trial (Swensen 1999, Harnish 2001), 40-kilometer time trial (Harnish 2001), maximal constant heart rate test (Vobejda 2005 and 2003), and the 30-minute cycling time trial (30CTT) (Friel 2006). The last four tests have been specifically identified for the easy of administration and need for very little equipment.

5-kilometer Time Trial. The 5-kilometer time trial (5kTT) followed by a 30-minute constant velocity test as described by Swensen (1999) and later validated by Harnish (2001) has been shown to be a valid estimation of the HR at MLSS. Athletes can complete a 5kTT at an all out effort. Then, they perform a 30-minute trial at 90% of the average speed from the 5kTT. The average HR during the MLSS test was 167+/-9.5 BPM and the average HR during the 30-minute test was 165+/-9.9 BPM and was not significantly different (Swensen et al 1999).

40-kilometer Time Trial. Harnish also included a 40-kilometer time trial for comparison and found the HR at MLSS was nearly identical to the 30-minute trial (174.7 +/- 2.6BPM vs 174.1+/-2.1 BPM respectively (Harnish 2001).
Maximal Constant Heart Rate. Vobejda and colleagues (Vobejda 2003, Vobejda 2005) have validated the maximal constant HR (MCHR) method in both cyclists and runners. For this test, cyclists start at a HR of 170BPM and maintain that HR regardless of workload for 30 minutes. If they can successfully maintain that HR they repeat the trial at 10 beats higher until they can no longer maintain the selected HR. After failing to complete a trial, the next 30-minute test is at 5 beats lower than the previous test. If the athlete is able to maintain the lower HR, the HR at MLSS is identified. If in the initial 30-minute trial, they are unable to maintain the HR of 170 BPM, the next and successive trials are performed at 10 beats lower until they can maintain the HR. The last trial is 5 beats higher than the first sustainable HR. While this test is simple, the number of trials is much higher than other methods and the authors do not recommend this method for beginner or low-trained individuals (Vobejda 2003).

30-minute Time Trial. The 30CTT is widely recommended and used (Friel, 2006, Perrey et al., 2003) for identifying HR_{LT} by taking the HR_{avg} over the last 20 minutes of a maximal steady state exercise bout. The advantage to using this model is the simplicity of the protocol and the need for a single testing session to determine the heart rate parameters by which an athlete will train. Although this method has been shown to be valid in determining the HR_{LT} in runners (McGehee et al., 2005), the validity in cycling is unknown. In a study on the transferability of HR between running and cycling, the authors found HRLT was up to 20 beats lower during cycling than running. The average intrasubject difference was 6.4 BPM (95%CI 5.4-
7.3 BPM) and the authors concluded that transferability between cycling and running is uncertain (Roecker 2002). Later, another study was done regarding the transferability of running and cycling training zones in triathletes. While there was no statistical difference between HR in cycling versus running, the error was 12 BPM, which was considered too high for practical use (Carey 2009). Groslambert and colleagues compared the physiological variables found in the 30-minute time trial to the individual anaerobic threshold method and VT. This study found that HR was a poor estimator of threshold HR due to cardiac drift, but they did not take the last 20-minute average, but rather the average of the entire 30 minutes of the time trial and they did not identify the HR\textsubscript{LT} at D-max which has since been shown to be a good estimator of MLSS (Groslambert 2004).

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 (Vobejda 2003) while others such as the 30CTT used by Friel (2006) 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. However, they used a fixed BLC of 3.5mmol/L to identify threshold (Denadai 2004).

This information coupled with the specificity of LT to the muscle groups used and the type of exercise (Beneke 2000) 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 heart rate monitor.

MATERIALS AND METHODS

PARTICIPANTS

Participants in this study will be individuals between 18 and 35 years old, and will be recruited from the mid-Willamette valley via fliers, word of mouth and email list-serve announcements. Individuals of all fitness levels will be encouraged to participate but must have competitive experience or aspirations. Approximately 40 participants will be recruited for this study. Approximately the same number of men and women will be included in the study to increase the generalizability of the findings across the two sexes. $VO_2^{\text{max}}$ will determine aerobic capacity as a descriptor of fitness.

Inclusion criteria: Participants must (1) have competitive/training aspirations or be a competitive athlete, (2) be between the ages of 18 and 35, (3) be able to ride a bike for minimum of 1 hour.

Exclusion criteria: Participants will be deemed ineligible for the study if they (1) have two or more cardiac risk factors as defined by the ACSM and AHA, (2) are planning to change training status during the scheduled testing period (3) are injured, (4) are unable to complete a maximal test.
Prior to the initiation of the study, IRB approval will be obtained, along with informed consent from participants.

*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 questionnaire. Participants must wait at least 24-hours between testing bouts to ensure recovery of muscle glycogen stores (Bergstrom, 1966). 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.

Prior to the initial test, individuals will complete a health history questionnaire to determine if they have risk factors for coronary artery disease as defined by the American College of Sports Medicine (Franklin, 2000, Penry 2008). Additionally, 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. It has been shown that minimal training effect occurs in a 6-week period of intense training (3-4% improvement in VO\textsubscript{2max}) (Carter et al., 2000)

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

PROCEDURES

Each individual will visit the lab on three to four occasions and will complete three tests: two GXT$_{\text{max}}$, and a 30-minute stationary cycling time trial. 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 a GXT$_{\text{max}}$. The third session will include a repeat GXT$_{\text{max}}$. The final session will the 30-minute stationary cycling time trial. Participants will be encouraged to give a maximal effort during each test.

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 variation diurnal variations in heart rate (Carter et al., 2002).

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 heart rate 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 CO₂ and O₂ prior to each test.

Participants will first complete a warm up and calibration stage. This stage includes steady cycling at minimal resistance for 10 minutes to warm up the bicycle tire to riding temperature. The CompuTrainer is then calibrated according to the manufacturer instructions. After calibration, the participant will begin a 3-minute warm-up stage. The wattage of the CompuTrainer during this warm-up stage will be constant between 80-200W depending on the body mass, gender and training status of the participant. The wattage will be selected to achieve a respiratory exchange ratio (RER) of approximately 0.70 during this warm up phase (table 2). 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 (Borg, 1982) at 3-minute increments beginning in the last minute of the warm-up stage. Following the warm-up period, the wattage will be increased by a percentage of body mass again, based on training status and gender (table 2). Participants will complete 3-minute constant load stages of increasing intensity until volitional exhaustion. Workload will be increased each stage according to the
participants ability to achieve a test length of approximately 18-21 minutes. Heart rate 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 levels. 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.

\( \text{VO}_2\text{max} \) is achieved if there is a \( \text{VO}_2 \) plateau evidenced by an oxygen uptake difference of less than 2.1 mL/kg from the previous stage (Franklin, 2000, Poole and Wilkerson, 2007). If a plateau is not achieved, the participants will then perform a verification stage (Meir, 2012). After a 10-minute cool down at minimal resistance, the workload will be gradually increased over a 2-minute period until the final intensity of the \( \text{GXT}_{\text{max}} \) is reached. After 1 minute, the workload will be increased to 105% of the maximal workload achieved in the \( \text{GXT}_{\text{max}} \). The subjects will be encouraged to continue for at least 2 minutes. The \( \text{VO}_2 \) plateau will be determined by comparing the final minute of the \( \text{GXT}_{\text{max}} \) 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 the 110% of the maximal \( W \) achieved in the \( \text{GXT}_{\text{max}} \).
In the literature, there are several ways to determine LT and thereby HR_{LT}. Each method is based on defining either the inflection point in the blood-lactate curve, a set BLC or a specific rise in BLC from baseline (Faude 2009). The method that will be used in this study is D-max (HR_{LT-D-max}) (Cheng et al., 1992). In addition, the ventilatory threshold (VT) will be identified by the V-slope method (Beaver et al., 1986) for reliability comparison.

*Time Trial:* The 30-minute stationary cycling time trial method will be used (Friel, 2006, Friel 2010). 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 intensity for 15 minutes. They will then begin a 30-minute time trial (30CTT). Workload will be adjusted throughout the 30CTT as needed by the participant, however they will be blind to the wattage. They will be asked to cycle at an RPE of 17 and will be asked to provide an all out, consistent effort for the duration of the 30CTT. Additionally, participants will be fan cooled and allowed to drink cool water ad libitum. Heart rate will be monitored continuously. The HR_{avg} during the last 20 minutes (HR_{30CTT}) will be used to determine HR_{LT}.

**STATISTICAL ANALYSES**

**Part One:**

*Reliability.* To determine reliability of the GXT_{max} a Bland-Altman plot will be used. This will examine differences between test trials. HR differences for the 2 test trials
will be plotted on the Y-axis, whereas the mean values for the 2 trials were plotted on the X-axis. One plot will be made for each variable HR_{LT}, HR_{VT} and VO_{2max}.

Part Two:

*Validity*. To determine concurrent validity, the HR_{LT} will be compared to the HR_{30CTT}.

To determine the strength of relationship between test scores and GXT_{max} performance, linear regression will be used. The standard error of estimate will be used to determine accuracy.

*Accuracy Across Fitness Levels*. To determine the accuracy of the 30-minute time trial across fitness levels, the error between HR_{LT} and HR_{30CTT} will be plotted against the respective VO_{2max} values.

Descriptive Statistics. Mean values and SDs will be calculated for all demographic data (age, height, weight, body composition and VO_{2max} values).

REFERENCES


31. Franklin BA: ACSM’s guidelines for exercise testing and prescription.


50. 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.


59. Roseguini BT, Narro F, Oliveira AR, Ribeiro JP: Estimation of the lactate...


70. 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

Australia 1996

