8-2000

A comparison of two lactate threshold protocols

Jason Glenn Langley

To the Graduate Council:

I am submitting herewith a thesis written by Jason Glenn Langley entitled "A comparison of two lactate threshold protocols." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Human Performance and Sport Studies.

David R. Bassett Jr., Major Professor

We have read this thesis and recommend its acceptance:

Edward T. Howley

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A COMPARISON OF TWO LACTATE THRESHOLD PROTOCOLS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Jason Glenn Langley
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ABSTRACT

During a progressive multi-stage running test, heart rate (HR) increases linearly with running speed. However, the HR eventually reaches a speed where it begins to level off Conconi et al. call the velocity at HR deflection (V_d) and they repot a close agreement (r = 0.99) between V_d and the lactate threshold or $LT_{discont}$ (using a test of there own design). Other researchers have compared V_d to continuous LT protocols (LT_{cont}), and have found that V_d overestimates LT_{cont}. In an effort to determine if the discrepancy results from the different LT protocols used, this study compared LT_{cont} to $LT_{discont}$ protocols. Additionally, this study compared V_d to LT on continuous and discontinuous tests. Seven trained runners completed four tests each: 1.) a $\dot{V}O_2$max test, 2.) a Conconi HR test conducted on a 400 m outdoor track with speeds increasing ~ 0.5 km/h every 200 m, 3.) an $LT_{discont}$ conducted on a 400 m outdoor track with six runs at predetermined speeds (3 above and 3 below) V_d and 4.) an LT_{cont} protocol with 3-min stages on a treadmill. There were significant differences ($P < 0004$) between $LT_{discont}$ (16.84 ± 1.72 km/h) and LT_{cont} (13 56 ± 2.29 km/h) The correlation between V_d and LT_{cont} was r = 0.86, while a correlation of r = 0.94 was found between V_d and $LT_{discont}$. In conclusion, Conconi's $LT_{discont}$ significantly over-estimates LT as determined by a conventional LT protocol (LT_{cont}). Therefore, the validity of the Conconi test must be questioned and V_d should not be used as an estimate of LT.

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INTRODUCTION

Lactate threshold (LT) has been shown to be the best physiological predictor of endurance performance (14,3) Typically it is measured by either continuous (28) or discontinuous (8,16) graded exercise protocols. Tests of different stage durations (29,28) have also been investigated. Attempts have been made to non-invasively determine LT by using % $\dot{V}O_{2max}$, % maximal heart rate (HR), and/or % HR reserve (13,27) A non-invasive field-test to estimate LT was proposed by Conconi et al. (8), and then validated against a discontinuous LT protocol.

In 1982, Conconi et al. published a paper titled "Determination of Anaerobic Threshold by a Noninvasive Field Test in Runners"(8), from that point on the test was referred to as the "Conconi Test". The purpose of the test was to determine, without the use of blood lactate samples, a runner's velocity at anaerobic threshold (AT). Anaerobic threshold was defined as "the highest $\dot{V}O_2$ beyond which lactate begins accumulating in the blood causing metabolic acidosis" (8). This was done by selecting the HR deflection point and the velocity (V_d) that corresponded to it. These investigators found that at slower speeds there was a linear relationship between HR and speed, which was already established in the literature, but they also found that at higher speeds HR began to plateau. They went on to report that this HR deflection point, or break from linearity, showed close agreement with the LT (8).

Conconi reported a successful determination of HR deflection, and therefore V_d, in 95-99% of trained runners (8,9). However, since nearly all runners show an LT, the failure to detect a HR deflection in some individuals is a limitation, without an identifiable breakpoint the test is of little use to either a coach or athlete. While the test does require a measured track, HR monitoring equipment, a stopwatch, as well as favorable weather conditions (21,2,15), validation of this protocol would eliminate the need for a treadmill, blood sampling and a lactate analyzer.

The importance of the current investigation as well as Conconi's original study lies in its practical application for developing and monitoring running programs for competitive runners. While elite runners may have access to an exercise physiology lab or training center, novice and amateur runners need a simple scientific approach to develop a training regime A runner may choose the Conconi test as the method of estimating LT and implement a training regimen based on the determined velocity. If the test is proven to be invalid, their training and race performance could be adversely affected.

Since Conconi's 1982 paper, over 30 studies have examined its practical value and many of them have attempted to independently validate the HR deflection point as a measure of LT Because the 30 studies have been inconsistent in their findings, Conconi et al. (9) was prompted to publish a review entitled "The Conconi Test: Methodology After 12 Years of Application" (9) They cited 18 investigations that were able to replicate the test (12,31), and 12 studies that did not (25). Recent studies including Vachon et al (24), Jones and Doust (18), and Leger and Tokmakidis (20) have shown that the HR deflection point over-predicts LT Yet to date no direct comparison has been done to validate the LT protocol used by Conconi.

Therefore, the purpose of this study was to determine the validity of the discontinuous LT protocol with 1200-m stages ($LT_{discont}$) used by Conconi against a conventional continuous treadmill LT (LT_{cont}) protocol. A secondary purpose was to compare the Conconi HR test (200-meter stages) and both the $LT_{discont}$ and LT_{cont} protocols. The hypothesis tested was that the Conconi discontinuous LT protocol significantly over-estimates velocity at LT in comparison to a continuous LT protocol with 3-minute stages. The hypothesis regarding the two secondary purposes was that the Conconi HR test will significantly over-estimate the velocity at LT, yet will be highly correlated with the $LT_{discont}$. This will be the first carefully controlled study to do a direct comparison between these two LT protocols.

Chapter II

REVIEW OF LITERATURE

Endurance Performance

Historically, maximal oxygen uptake ($\dot{V}O_{2max}$) was viewed as a good predictor of performance in endurance events (23). This relationship led to "training programs … designed to improve $\dot{V}O_{2max}$, with intensity of training usually based on a given percentage of $\dot{V}O_{2max}$, maximal HR, or HR reserve" (1). Within the past 20-30 years research on the prediction of endurance performance research has been redirected towards a multi-component model. Recently a diagram has been proposed in an attempt to explain running performance in distance races (Figure 1). In this model $\dot{V}O_{2max}$, percentage of $\dot{V}O_{2max}$ at LT (% $\dot{V}O_{2max}$), and running economy contribute to the running velocity at which LT occurs and in a practical sense the maximal velocity a runner can maintain during a distance race. These three components will be outlined as the basis for the specific discussion of lactate threshold and the Conconi test.

$\dot{V}O_{2max}$ sets the upper limit of performance in endurance events. In other words, it is impossible to run a marathon or any other endurance event at or above 100 % of $\dot{V}O_{2max}$. Costill et al. (11) demonstrated the strong negative correlation (r= -0.91)

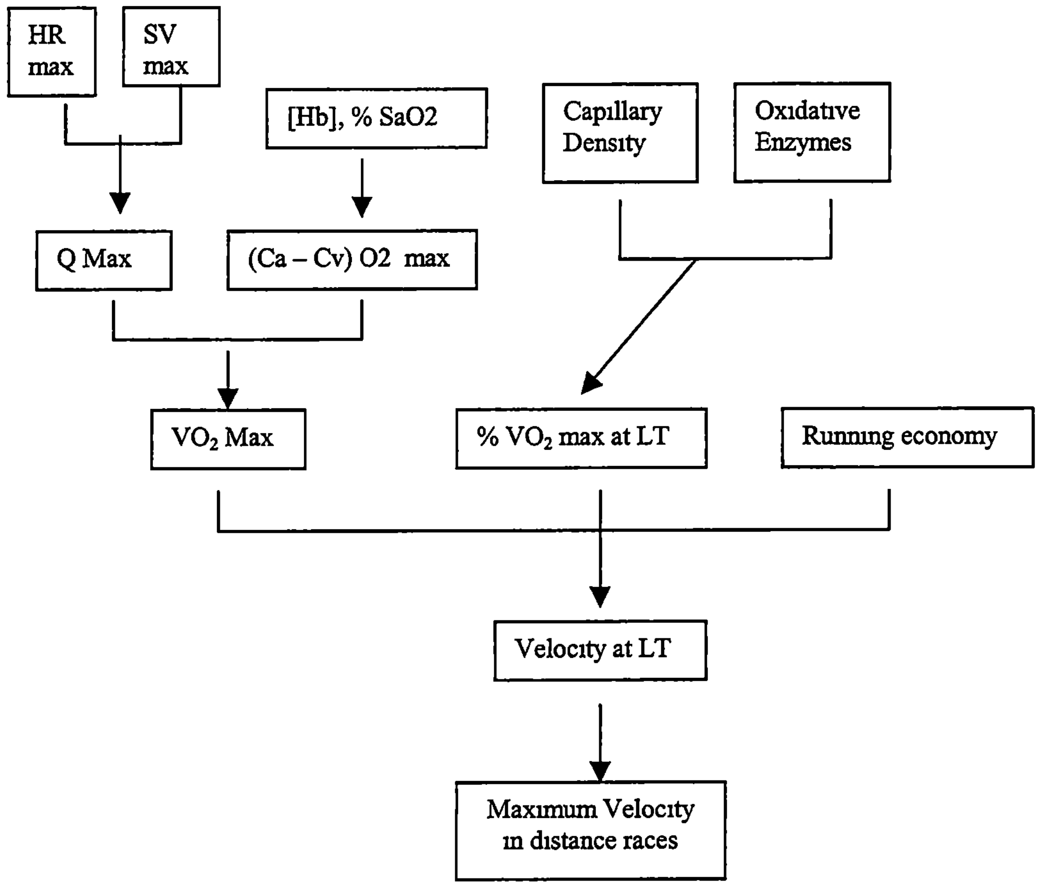

Figure 1. Factors affecting running performance.a
a Modified from (4)

shown between $\dot{V}O_{2max}$ and time to complete a ten-mile run (Figure 2). However, this does not explain who will win a race among a homogeneous group of runners with similar $\dot{V}O_{2max}$ values. The explanation resides in a runner's economy and the $\%\dot{V}O_{2max}$ that they can sustain while competing.

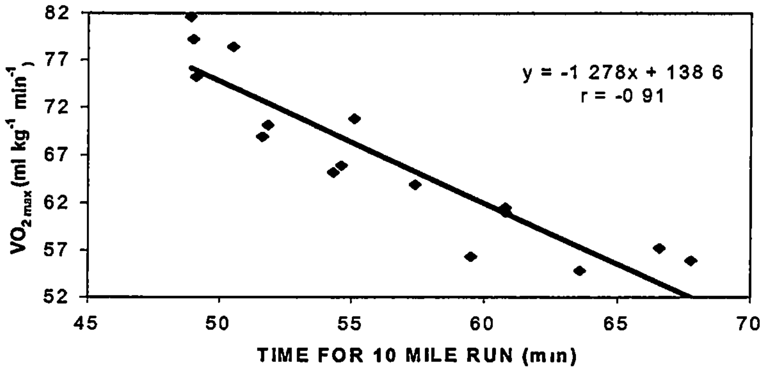

Figure 2. (11) The relationship between maximal oxygen consumption and distance running performance

Running economy was first recognized and described by Hill and Lupton in 1923. They stated, "A man may fail to be a good runner by reason of a low oxygen uptake, a low maximum oxygen debt, or a high oxygen requirement; clumsy and uneconomical movements may lead to exhaustion just as well as may an imperfect supply of oxygen" (17). Running economy has been described as steady-state $\dot{V}O_2$ ($ml \bullet kg^{-1} \bullet min^{-1}$) for a standardized speed (14), with the more economical runner having a lower $\dot{V}O_2$ at equivalent speeds. Thus the runner with the lowest $\dot{V}O_2$ among a group of runners running at the same speed will have an advantage. This was confirmed by Conley and Krahenbuhl and is shown in figure 3 (10).

As described by Hill, the percentage of $\dot{V}O_{2max}$ that a runner can maintain over the duration of an endurance event is more representative of the oxygen uptake available for energy production during an endurance run because runners are unable to maintain

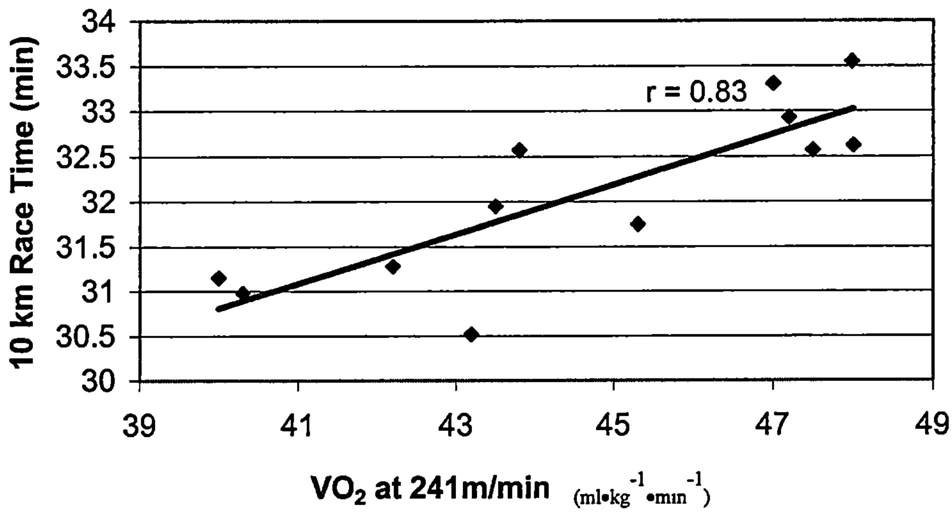

Figure 3. Correlation between $\dot{V}O_2$ at 241 m/min and 10 km race performance

100% of maximal oxygen uptake (17) This means that a runner running at a higher $\%\dot{V}O_{2max}$ will likely beat a runner of equal $\dot{V}O_{2max}$ running at a lower $\%\dot{V}O_{2max}$. Costill (11) showed that the $\%\dot{V}O_{2max}$ that can be sustained is correlated with LT, which was later verified by Farrell (11,14). The percent of $\dot{V}O_{2max}$ a runner can maintain is determined by measuring lactate threshold.

Table 1 shows an example of two runners with identical $\%\dot{V}O_{2max}$ values (85%). Subject A has a higher $\dot{V}O_{2max}$ but lower economy (represented by a higher $\dot{V}O_2$ at 16 kilometers per hour (km/h)), while Subject B has a lower $\dot{V}O_{2max}$ and higher economy. However, both runners have the same predicted marathon running speed.

This formula used to predict marathon-running speed was developed by Joyner (19). The equation contains each of the three components previously described as predictive of endurance running performance and is as follows: Marathon running speed = $\dot{V}O_{2max}$ (ml•kg^{-1}•min^{-1}) x %$\dot{V}O_{2max}$ at LT x RE ((km/h)/ $\dot{V}O_2$). Since all three variables can be used to predict performance, research has been done in an attempt to determine which factor contributes the most to predicting performance. Using a multiple regression model to determine which predictor would be most important, Farrell showed that the onset of plasma lactate accumulation (OPLA) "accounted for between 82.8% (3.2 km race) and 96% (42.2 km race) of the variance in performance" (14).

Table 1 Prediction of marathon running speed

Subject	$\dot{V}O_{2max}$	%$\dot{V}O_{2max}$ - 85% of 70 ml•kg^{-1}•min^{-1} & 65 ml•kg^{-1}•min^{-1}	Running Economy- $\dot{V}O_2$ at 16 km/h	Predicted marathon running speed	Predicted Winner
A	70 ml•kg^{-1}•min^{-1}	59.5 ml•kg^{-1}•min^{-1}	55 ml•kg^{-1}•min^{-1}	17.3 km/h	Possible
B	65 ml•kg^{-1}•min^{-1}	55.3 ml•kg^{-1}•min^{-1}	51 ml•kg^{-1}•min^{-1}	17.3 km/h	Possible

Definitions of Lactate Threshold

As the focus was placed on LT, researchers introduced a number of terms to refer to the sudden increase in blood lactate during a general exercise test (GXT). These include LT, maximal steady state, anaerobic threshold (AT), individual anaerobic threshold, lactate breakpoint, and onset of blood lactate accumulation (OBLA). While these terms all describe the measurement of blood lactate, the absolute intensity ($\dot{V}O_2$, velocity, or HR) may be significantly different upon a closer look at the specific definition used. Figure 4 demonstrates a typical continuous LT protocol conducted in a laboratory setting with blood lactate concentration graphed on the Y-axis and velocity in km/h graphed on the X-axis. The specific definitions for LT are labeled the breakpoint (A), a 1 mM increase from baseline (B), a specific lactate concentration of 2.5 mM (C), and OBLA (a lactate concentration of 4.0mM) (D). As depicted in the graph below, breakpoint (A) is the highest velocity achieved prior to the curvilinear response shown. B is the point at which lactate concentration has risen 1 mM above the baseline values. Points C and D correspond to specific blood lactate concentrations of 2.5 and 4.0 mM, respectively. Yoshida et al. (30) compared several of these definitions to determine which most accurately predicted performance. The study involved riding a cycle ergometer with 20- watt increases

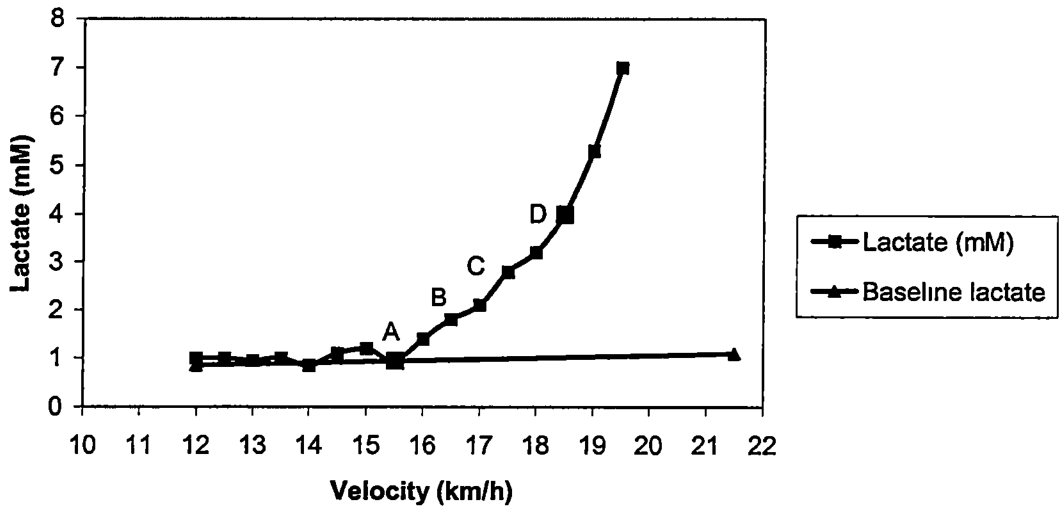

Figure 4- Velocity differences usıng varıous definitions.

every four minutes until volıtional exhaustıon. They found that the breakpoint method of determınıng LT was most highly correlated wıth both $\dot{V}O_{2max}$ and 12-minute run performance ın comparison to a 1 mM increase from resting baseline, or fixed lactate values of 2.0 or 4.0 mM. This emphasızes that the method of selectıng the LT must be chosen prior to ınıtıatıng the project and must be sımılar to the point used in the comparison protocol. In the current investigatıon, the breakpoınt method was used for the LT_{cont} protocol, in contrast to a mathematıcal model used by Conconı et al. (8). Conconı's method for determınatıon will be dıscussed in detaıl under the discontinuous LT protocol in Chapter 3.

Lactic Acid Metabolism and Blood Lactate Response During Exercise

After dıscussing the importance that blood lactate has as a predıctor of performance, it is important to remember that blood lactate is present at all times ın the body, evidenced by values near 1 mM even under resting conditions. Of course, the focus of this study will involve its importance during exercise. Also of importance is the fact that blood lactate accumulation is a positive net result of production and removal, or rate of appearance and rate of disappearance (6).

Figure 5 highlights lactate production. Glucose enters the cell and is broken down through glycolysis with lactate being the end product that is transported outside the cell to the blood. Lactic acid accumulation is responsible for detrimental consequences in terms of endurance performance because as depicted in Figure 5 a matching hydrogen ion (H^+) is also produced.

Upon reaching the blood, some of the lactate is transported to the liver where glucose is re-formed via gluconeogenesis (Figure 6). The glucose then enters the blood and is returned to the muscle for additional energy production. This has been named the Cori cycle.

While the liver is a primary site for lactate removal, heart and skeletal muscle tissue have also been shown to take-up and use lactate According to the tracer studies of Brooks, about 75% of the lactate produced during prolonged steady-state exercise is oxidized, while 25% is reconverted to glycogen (5). If the level of production exceeds the level of removal, then lactate begins to accumulate in the blood. The accumulation of lactate in the blood can have detrimental consequences on vital areas of the body such as the muscle, brain, and lung tissue. It is this H^+ as well as the hydrogen ion generated during the breakdown of ATP in the muscle that lowers pH.

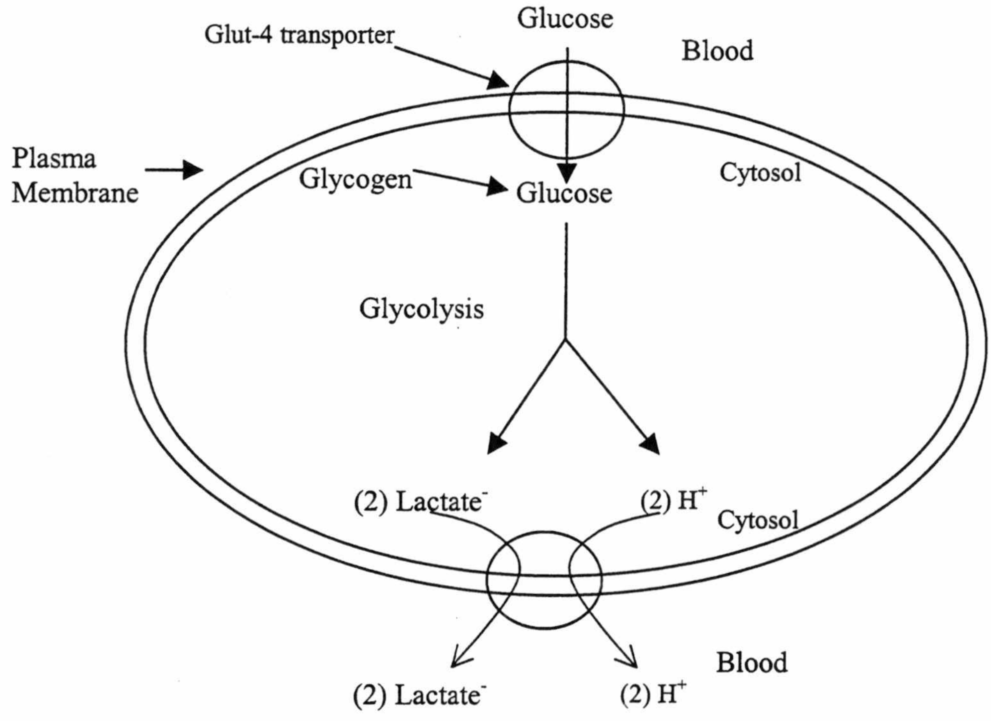

Figure 5. Lactate production within a muscle fiber.

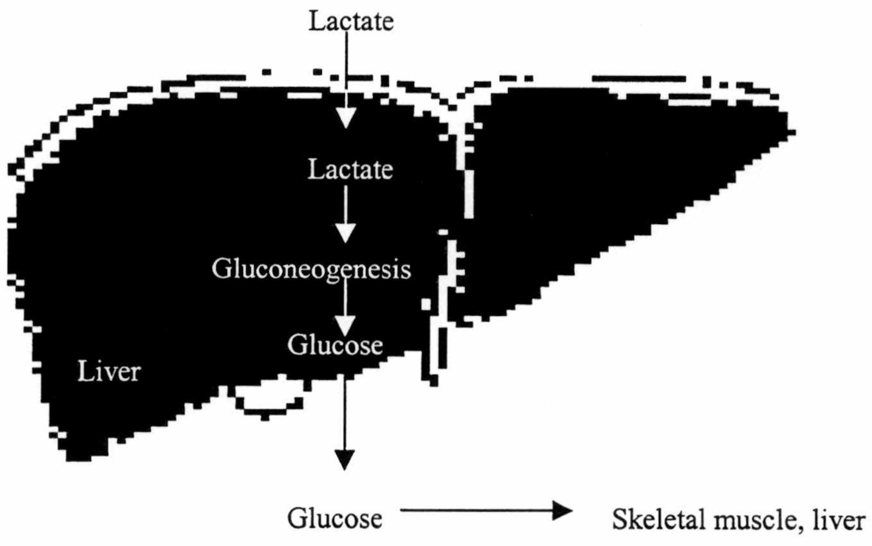

Figure 6 Lactate removal- Cori cycle.

The lowering of pH can specifically inhibit the glycolytic rate-limiting enzyme phosphofructokinase (PFK) thus limiting ATP production. In terms of muscle contraction, H^+ may interfere with Ca^{2+} binding to troponin, which is the loading step. This step is a key event in excitation coupling (5). The reaction of H^+ in the brain can also cause pain, nausea, and disorientation. Within the lung, H^+ again interferes with association of oxygen and hemoglobin. Another significant consequence, especially to runners participating in the marathon (2+-hour event), is the inhibitory effect of H^+ production has on hormone-sensitive lipase (HSL). HSL is responsible for the eventual release of free fatty acids into the blood (5). Without this major source of fuel, impairment in muscular contraction, and effects on balance it is very evident that running at or below LT is crucial to success in an event such the marathon.

<u>Validity of the Conconi Test</u>

Attempts to replicate the Conconi test have met with both success and failure. The following sections will provide examples of both successful and unsuccessful studies involving the Conconi protocol.

After the publication of the original Conconi study (8), investigators began to apply the test to other endurance events. Droghetti et al. (12) conducted tests on canoeists, cross-country skiers, cyclists, walkers and both roller and ice skaters. Utilizing a similar Conconi test adapted for each event they found a coincidence between V_d and the onset of blood lactate accumulation and the test therefore permits the indirect noninvasive determination of velocity (12). The use of Conconi's unconventional LT protocol limits the reliability of their findings. Cellini et al. found similar results in swimmers (7). V_d and LT were again correlated (r = 0.84). This study used a slightly modified discontinuous LT, whereas two speeds were chosen above and below V_d and a single speed at V_d. These studies are of interest, but without comparison to a standard method of determining LT, they must be accepted with caution. Traditional running LT protocols are available, so studies attempting to use the Conconi's $LT_{discont}$ in its original format for runners should provide greater evidence to its validity.

Maffuli et al. compared slope variation point (SVP) (equivalent to V_d) to LT and found the correlation coefficient to be r = 0.95 (22). This result is to be questioned due to the use of a treadmill for conducting the Conconi test and because the same modified Conconi 1200-m test used by Cellini was used to determine LT. Maffulli also did not use Conconi's model for selecting LT; instead they used a traditional definition- the point at which a non-linear increase of blood lactate occurred (22).

These studies represent a subset of studies reviewed by Conconi (9) and determined to be "successful" replications of his test. It is apparent that while producing findings similar to Conconi, these studies did not use the procedures developed by Conconi It would be crucial to conduct both the Conconi HR test and $LT_{discont}$ on a 400-m track and not on a treadmill because otherwise it defeats the purpose of developing a field test.

The discontinuous nature of Conconi's 1200-meter protocol has been questioned because typically a standard laboratory protocol is continuous. Leger and Tokmakidis found a very low correlation (r = .5) between LT and the Conconi 200-m test (20). If there were a high correlation between $LT_{discont}$ and V_d, as Conconi et al. (8) reports, this supports the hypothesis that Conconi's 1200-m LT protocol (using V_d) over-estimates LT during a continuous protocol. Although Leger and Tokmakidis used a 183.9 m banked indoor track for both tests making it difficult to compare it to Conconi's findings. Leger and Tokmakidis (20) also challenged Conconi's method for selecting LT. They were concerned that the point where two linear curves cross contradicts research showing a curvilinear increase in lactate (20). Leger and Tokmakidis went on to state that by using this method the crossing point "will always fall between stages 3 and 4, which is always near the HR threshold" (20). Conconi responded by stating "in fact the line connecting the points above V_d could have several inclinations and intercept the other line anywhere from the origin up to stage four" (20). Conconi et al. (8) gave little reason for the low correlation observed by Leger and Tokmakidis (20) except that additional equipment (mask for $\dot{V}O_2$ measurements) was worn during the continuous protocol.

In 1997 Jones and Doust (18) examined both the Conconi HR test and a continuous LT test on a treadmill, finding results similar to those of Leger and Tokmakidis. Their study showed significant differences between V_d and velocity at LT during a continuous treadmill test. However they did not follow Conconi's HR-protocol; instead they used a treadmill with a 1% grade to compensate for a lack of wind resistance A second part of the study attempted a performance test using the results from both methods of determining LT. Seven subjects completed two additional 30-minute runs on a treadmill that were set to .5 km/h below the LT determined by both protocols. All seven were able to complete the run set slightly below the continuous LT velocity protocol but only 1 subject was able to complete the full 30 minutes at .5 km/h below V_d (mean time to exhaustion 15.9 ± 6.7 min). Terminal lactate values of 2.4 ± 0.5mM (cont LT) and 8.1 ± 1.8mM were measured for the continuous LT and V_d, respectively. It was also reported that during the test conducted at a speed slightly below V_d lactate values never reached a steady state and gradually rose throughout the test.

In a study done at the University of Tennessee, by Vachon et al. (26) results similar to those of Leger and Tokmakidis (20) were found. These researchers found a slightly higher correlation (r = .68) between velocities determined by Conconi's HR test and by a continuous LT test (26), yet far below the correlation (r =.99) reported by Conconi (8) These researchers had runners complete three tests: a Conconi HR test on a track, a constant stage HR protocol on the treadmill and continuous LT test on a treadmill Results from these two tests indicated a deflection in HR in all subjects during the track test but a deflection in only half of the subjects during the treadmill test (26). Having shown a significant difference in V_d and the velocity at LT during a continuous protocol, these researchers proposed that further research was needed to determine the validity of the Conconi 1200-meter discontinuous LT test used in validating the original Conconi test

Chapter III

METHODS

Eight competitive male runners in the Knoxville, TN area participated in the study. The subjects were tested in two groups. The mean age (±SD), height, body mass, and $\dot{V}O_{2max}$ were 25.5 ± 5.1 years, 178.5 ± 6.2 cm, 73.9 ± 6.0 kg, and 61.99 ± 9.88 ml•kg^{-1}•min^{-1}, for group A (subjects 1-3) and 31. ± 7.3 years, 181 ± 6.4 cm, 73 ± 9.0 kg, and 61.81 ± 7.59 ml•kg^{-1}•min^{-1} for group B. Subjects were required to be highly trained as defined by running greater than 25 miles per week. In addition, the participants completed a Physical Activity Readiness Questionnaire (24). The minimum running distance and PAR-Q were used to reduce the likelihood of including an individual for whom the testing may be contraindicated.

During the initial visit each subject reported to the Applied Physiology Lab on the University of Tennessee campus and testing procedures were described in detail. At this time the subjects read and signed an informed consent form (Appendix A) that outlined each of the four tests and the risks and benefits associated with participating. Next they were familiarized with running on a treadmill (if necessary), and then given a brief explanation about the mouthpiece apparatus used to measure $\dot{V}O_{2max}$, and the blood sampling techniques to be used.

The ordering of the four protocols was partially randomized with the first test being either a $\dot{V}O_2$ max test or the Conconi test. The only specific requirement for randomizing the tests was that the $\dot{V}O_2$ max test preceded the continuous LT test and the Conconi test preceded the discontinuous LT protocol. The HR deflection point was determined from the Conconi HR test prior to setting the speeds used during the discontinuous LT test. Similarly, $\dot{V}O_{2max}$ aided in setting the initial speed for the continuous LT test.

To insure maximal effort and accurate results, the subjects were instructed to avoid extended or high-intensity workouts 24 hours prior to each of the four tests, and individual testing sessions were separated by at least 48 hours. The subjects wore the same running shoes and similar clothing for each of the tests and were weighed prior to each testing session. Environmental conditions were controlled as tightly as possible. Ambient temperature and relative humidity were monitored and recorded prior to and immediately after both lab and field tests. If necessitated by significantly different temperature and/or humidity, (which was determined prior to testing in the field) tests were rescheduled when environmental conditions were more similar to the laboratory. Mean lab temperature (± SD), and relative humidity, were 22 ± 2.02°C and 55 ± 9.59%. For the field trials, the values were 23 ± 3.01°C and 69 ± 18.45%, respectively.

$\dot{V}O_2$ max test

The $\dot{V}O_2$ max test was a constant speed protocol with a one percent increase in grade at one-minute intervals to elicit the desired response on a treadmill. Five subjects were tested using a computerized metabolic cart (Parvomedics, True Max

2400 Metabolic Measurement System). Three subjects were tested using a Rayfield System using Applied Electrochemistry O_2 and CO_2 gas analyzers and a RAM 9200 airflow meter integrated by an Apple IIe computer. During the 4-5 minute warm-up period an initial speed was chosen that would elicit volitional exhaustion in each subject within 7-10 minutes of the initiation of the test. The grade was increased 1% each minute until the subject could no longer continue. Each subject was encouraged to attempt to complete the entire one-minute stage. A confirmation of maximal effort was determined by the attainment of at least three of the following criteria: (1) an R value of greater than 1.15, (2) a HR within 10 bpm of age predicted max HR, (3) a post-test blood lactate of 8 mM or greater (within 3-minutes post-completion), and (4) a plateau in $\dot{V}O_2$ with subsequent stages (less than 50% of an expected increase in $\dot{V}O_2$). Fingertip samples (200 microliters) were collected within 3 minutes after termination of the test and analyzed for lactate. The blood was immediately transferred to a YSI lactate sampling tube containing an antiglycolytic (sodium fluoride) and a cell-lysing agent (cetrimonium bromide), and the tube was shaken to ensure the mixing of the reagents. A StatPlus 2300 (Yellow Springs Instruments; Yellow Springs, OH) automated lactate analyzer was used for all measures of blood lactate.

Conconi 200-meter HR Protocol- "Conconi Test"

This protocol includes a number of consecutive 200-meter runs, in which each runner increases his running speed (RS) approximately 0.5 km/h for each interval (8). Prior to each test the investigator calculated a set of split times for each individual runner to achieve. The speeds corresponded to the fitness level of the individual runner and his personal knowledge and experience in running timed workouts. Initial RS were 10-14 km/h for all subjects. The test was terminated when the participant was unable to complete consecutive splits at the required speed. A Robic SC800 Sports chronograph with the capability of recording multiple split times was used to record times for later analysis.

Heart rate was determined and recorded using a Polar Vantage XL heart monitor. The HR watch was set to record at five-second intervals. The average HR over the last ten seconds of each 200-m stage was used to compile the graph used for analysis and determination of the HR deflection point. Both the Robic and the Polar watch were started simultaneously to ensure data was collected over the same time period and that the HR corresponded to the appropriate RS. The split times were retrieved from the Robic watch and graphed with reference to the HR measured over the same time period.

The speed at which LT occurred was determined to be equal to the deflection in the typically linear HR response seen with an increase in workload (Figure 7). Velocity at the deflection point has been proposed by Conconi to be equivalent to the "anaerobic threshold" (8).

Discontinuous Conconi LT test

Each subject performed a discontinuous LT test using the protocol of Conconi et al. The investigator chose three speeds above and below the previously determined V_d. Stage one began at approximately 5 km/h below V_d; stages two and three were set to 1 5 and 3 km/h higher than stage one, respectively. Stage 4 was set to one-half km/h

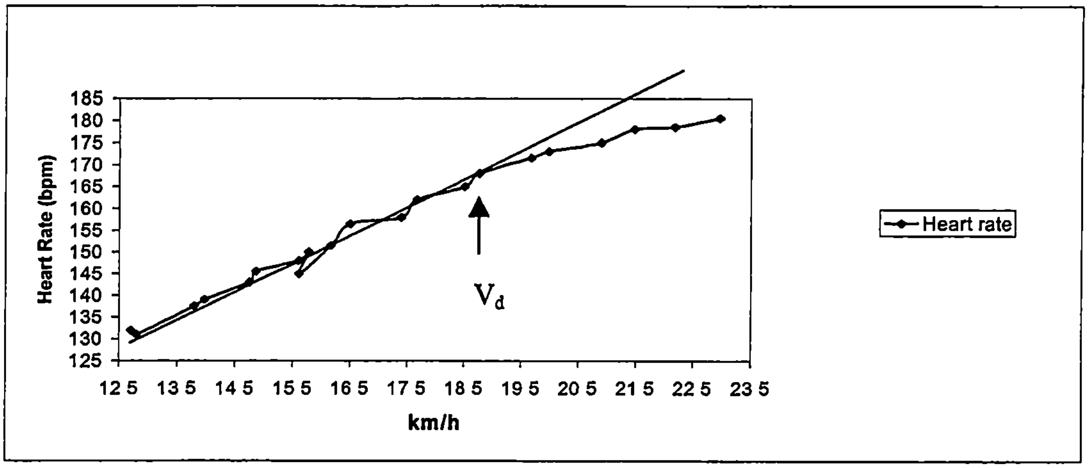

Figure 7. Example of a Concom HR test.

above V_d, and stages 5 and 6 were set to 1 and 2 km/h, respectively, higher than stage four. A resting lactate sample was taken prior to the initiation of this protocol.Each 1200-meter run was separated by a recovery interval of five minutes of seated rest and 12-15 minutes of light jogging. Four to five minutes after exercise a 1-ml venous blood sample was taken from a forearm vein and treated as previously described. After completing the light jog the subject then continued with the remaining runs.

Similar to Conconi's 1982 paper, LT was determined using a mathematical model shown in Figure 8. This model involved the summing of regression line A (Sub-V_d, stages 1-3) and line B (Supra-V_d, stages 4-6). The point at which the two regression lines cross was the velocity considered to be the LT.

In the example below the speed using Conconi's mathematical model would be 14.89 km/h.

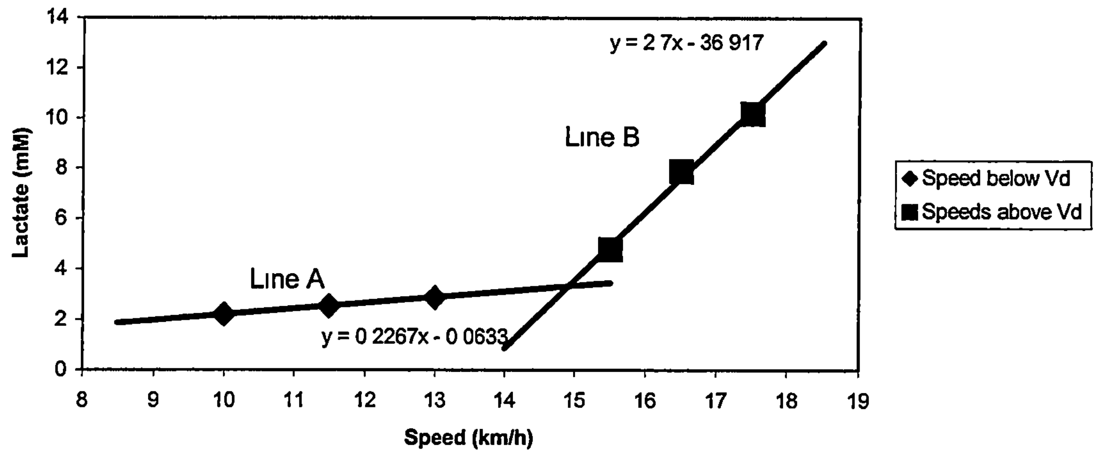

Figure 8. Example of a Concom $LT_{discont}$ test.

This was derived from the following steps:

1.) $2.7x - 36.917 = .2267x - 0.0633$

2.) $2.4733x = 36.85$

3.) $x = 14.89$

Continuous Treadmill LT test

A conventional continuous LT (LT_{cont}) protocol was also performed. The treadmill test started at a speed (9 6 km/h in 5 subjects, and 11.3, 12.1 and 13.7 km/h in one subject each) that would allow the subject to complete 9-10 stages prior to reaching volitional exhaustion Each three-minute stage was run at a constant speed and 0% grade (28). An incremental increase of ~.8 km/h was used for successive stages, and the subject was encouraged to complete the full three minutes of the final stage before stopping due to fatigue

With one minute remaining in each stage, the blood collection was begun, with the actual sample being drawn during the last 15 seconds of the stage. Blood was withdrawn from a forearm vein by an in-dwelling catheter unit, consisting of a Teflon catheter connected to a 20-inch small bore extension tube with a three-way stopcock attached as the blood-collecting syringe interface. Patency of the sampling line was maintained using 6-7 ml of 0.9% saline in aqueous solution. A 0.5-1.0 ml blood sample was collected for analysis using the previously described procedure and automated lactate analyzer.

The lactate (Y-axis) values were graphed versus their respective velocity (X-axis) in Figure 9. According to Weltman's procedure, a straight line was drawn through points considered baseline values with the remaining points being fit to a smooth curve. LT was designated as the highest velocity before an elevation in blood lactate concentration above baseline was seen (28).

In Figure 9, 13.67 km/h would be selected at LT according to the definition chosen.

Statistical Analysis

Data were analyzed using an SPSS statistical package, version 10. A two-tailed paired Student's t-test (dependent t-test) was used to examine differences between velocity at $LT_{discont}$ and velocity at LT_{cont}. The V_d measured during the Conconi HR test was also compared to the velocity at $LT_{discont}$.

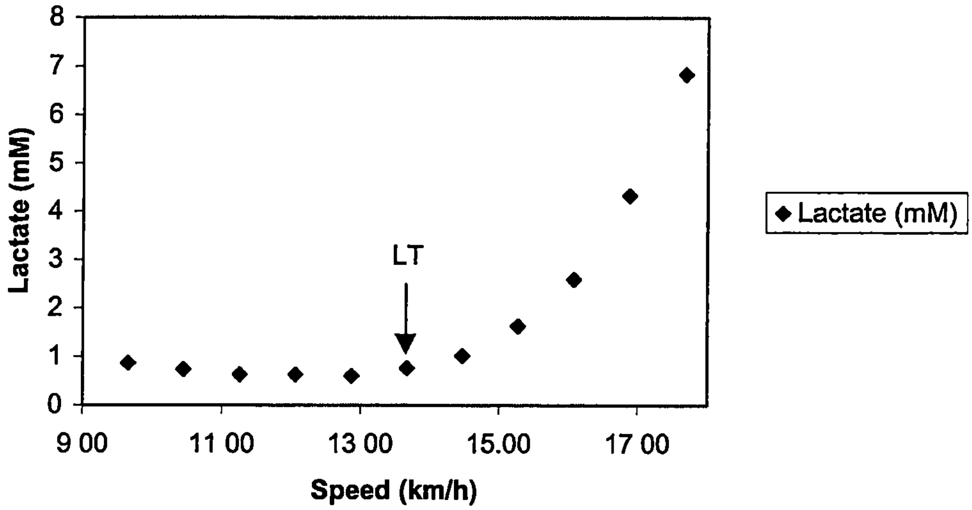

Figure 9. Example of Continuous LT test.

Chapter IV

RESULTS

Eight subjects completed the four testing protocols. The two protocols used by Conconi were adhered to in all cases except during $LT_{discont}$ test of subject 6, where capillary blood sampling replaced venous blood and in subjects 3, 7, and 8 where only 5 samples were collected in each case due to difficulty in attaining a sample. The data for subject 8 was not used for statistical analysis due to an unknown error in the measurement of lactate (Appendix P). As hypothesized, Conconi's 1200-meter lactate threshold test significantly over-estimated the velocity at LT in comparison to a traditional LT protocol. The velocities at $LT_{discont}$ and LT_{cont} occurred at speeds between 14.58–18.89 km/h and 10.45-16.08 km/h, respectively (Table 2). Due to the fact that a speed at $LT_{discont}$ for subject 8 was determined, the data from only 7 subjects was used for analysis. This statistical analysis revealed a significant ($P < .0004$) difference between $LT_{discont}$ and LT_{cont}. The relationship between the two

Table 2. Speeds corresponding to LT_{cont} and $LT_{discont}$

Subject	LT_{cont} speed km/h	$LT_{discont}$ speed km/h
1	16.08	18.89
2	15.28	17.89
3	10 45	16.00
4	12.86	16.53
5	12.86	14.58
6	12.06	15.22
7	16.08	18.80
8	13.67	Not available
Mean ±SD	13 56 ± 2.29	16.84 ± 1.72*

*Statistically significant ($P < .0004$)

speeds (r = .84) is graphed in Figure 10. Having the V_d data from the Conconi test, a correlation (r = .94) was determined between V_d and $LT_{discont}$. This result is similar that of Conconi et al. (r = .99) (8). The final relationship between V_d and LT_{cont} had a correlation coefficient (r = .86).

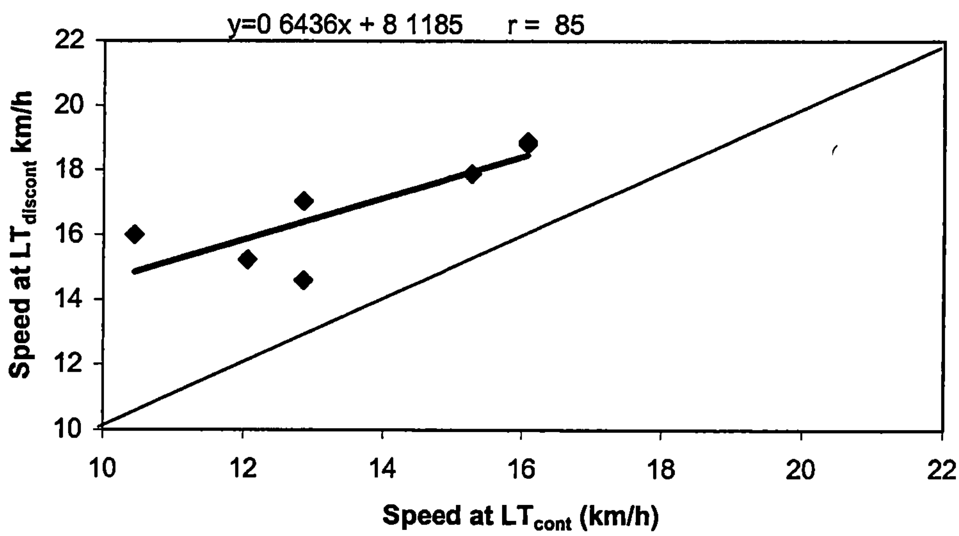

Figure 10. Relationship between LT_{cont} and $LT_{discont}$.

Figure 11 graphically shows Subject 1's V_d, speed at LT_{cont}, and $LT_{discont}$. Clearly V_d and $LT_{discont}$ line up nearly perfectly but are significantly higher than LT_{cont}. Individual data and figures for each of the 8 subjects can be found in appendices B-Y.

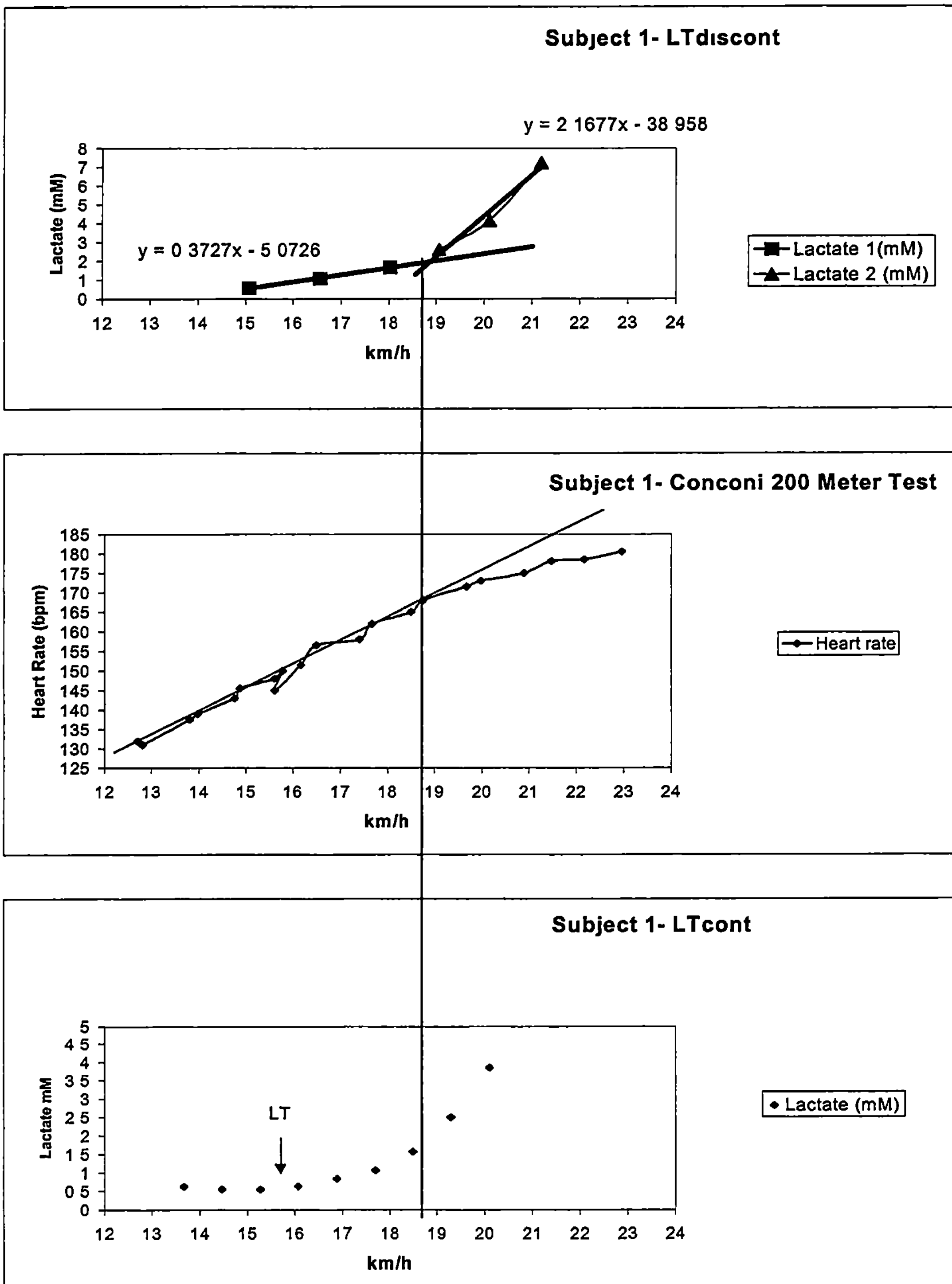

Figure 11. Subject #1's V_d, LT_{cont}, and $LT_{discont}$

Chapter V

DISCUSSION

Since its publication in 1982 the Conconi test has been challenged by a number of researchers. The first criticism was that other researchers were unable to replicate the close agreement between LT and HR deflection observed by Conconi et al. (8). I hypothesized that the discrepancy between studies was related to the unique nature of the protocol employed by Conconi et al. (8). This investigation focused on three determinants of LT: (1) Conconi's HR deflection test (2) a conventional continuous LT test and (3) LT as determined by Conconi's discontinuous protocol. The results of the present investigation confirm Conconi's finding that $LT_{discont}$ and HR deflection are indeed very similar, but neither are comparable to LT_{cont}.

A number of researchers have compared continuous and discontinuous LT protocols on a treadmill. Hagberg et al. proposed that a series of 10-min stages should be used as the standard for measuring blood lactate because, the length of the stage should allow time for lactate to diffuse (16). They allowed a minimum of 15 minutes between stages to allow blood lactate levels to return to near-resting values. To ensure the return to near resting values, a pre-exercise sample was taken prior to beginning the next stage (16). This protocol involved several visits to a laboratory, which could be seen as a major disadvantage if the same results could be found in a single visit.

Weltman et al. (28) compared a continuous LT protocol (3-min stages) to the discontinuous LT test described by Hagberg. Weltman et al. found no significant differences (mean ± SD, continuous, discontinuous) in $\dot{V}O_2$ (52.28 ± 5.20, 52.38 ±

6.33 ml•kg^{-1}•min^{-1}) or velocity (232.5 ± 26.0, 236.3 ± 28.7 m/min) at LT between the two protocols. Therefore, they concluded that a continuous 3-min protocol could be used to accurately determined LT. The advantage to this protocol is that it requires only 1 visit to the laboratory.

The $LT_{discont}$ protocol of Conconi et al. (8) differs from both of the established (continuous and discontinuous) protocols. With the Conconi protocol, the stage duration decreases from between 6 and 7 minutes to 3-4 minutes, as the test proceeds. Thus the stages are only half as long as those seen in a typical discontinuous protocol (10-min stages). These shorter stages may result in less accumulation of lactic acid, causing a shift in LT to the right. This assumption is supported by the finding that the mean velocity at LT_{cont} was at 13.56 km/h, while Conconi's $LT_{discont}$ occurred at a speed of 16.84 km/h.

The differences between the actual LT_{cont} and $LT_{discont}$ tests are apparent when attempting to apply the velocity at $LT_{discont}$ to the curve generated by the LT_{cont}. The mean lactate ± SD was 4.3 ± 3.1 mM, with a range of 2.09-9.0 mM. These values demonstrate that for some individuals $LT_{discont}$ will elicit relatively low lactate values, but in other runners this velocity will result in elevated lactate levels. Two examples can be seen in subjects 1 and 6.

When applying the velocity at $LT_{discont}$ to the LT_{cont} curve generated by subject 1, a value of 2.3 mM is found, a seemingly valid value. However, this is not the case in subject 6 where a lactate value of 8.5 mM is found, a suspected near max value.

The practical implication this has on training and racing has to do with pace. One would expect subject 1 to be able to maintain the pace predicted by the $LT_{discont}$ test for an extended period of time, while subject 6 will not.

The issue of performance was examined by Jones and Doust (18). When subjects ran at the speed equal to 0.5 km/h less than $LT_{discont}$ the mean time-to-exhaustion was 15 minutes. On the other hand, all subjects were able to complete a 30-min run at 0.5 km/h below LT_{cont} (18). Post-exercise lactate samples revealed values of 8.1 mM and 2.4 mM for HR deflection and LT_{cont}, respectively. The high blood lactate values found after the run at slightly below V_d prove that this speed is well in excess of the LT.

Another weakness of Conconi's protocol, according to a few investigators, is that 50-90% of runners fail to show a HR deflection (26). This is in stark contrast to the 95-99% reported by Conconi and co-workers (9). In addition, Conconi's HR test has been criticized because as the duration of the 200-m stages grow increasingly shorter and thus during the final stages there may not be adequate time for achieving a steady-state HR. In response to this criticism, Conconi's 1996 paper made alterations to the original test protocol. The major difference was stages were based on a fixed time rather than a fixed distance (9). Using a fixed time instead of a 200-meter distance seems to answer questions regarding achieving a steady state HR with stages of increasingly shorter duration. Vachon et al. found that all runners show a HR deflection during Conconi's HR test but only of them show a HR deflection during a treadmill protocol (60-second stage) (26). Believing there was adequate time for HR to adapt to each speed even during the final stages of the test; they hypothesized that decreasing stages did not allow time for lactate to accumulate. Thus, the subjects continued at their maximal HR with the predominant source of fuel coming from anaerobic sources (26).

The final criticism concerns the mathematical model used by Conconi to detect LT. They used a non-randomized, discontinuous protocol, in which V_d is used as a reference point for setting the speeds for the $LT_{discont}$ test. Other authors contend this increases the likelihood of finding a high correlation between the two tests (20). Their concerns also include using the point where two linear curves intersect, which contradicts the substantial amount of research indicating a curvilinear increase (20). While I believe these are valid concerns my focus was on the discontinuous nature of Conconi's $LT_{discont}$ protocol.

Conconi et al. (8) has continued to use anaerobic threshold (AT) when describing LT. It will be difficult to apply any of the generally accepted definitions of LT to Conconi's hybrid $LT_{discont}$ because of the use of a point connecting two lines. A traditional smooth LT curve allows for the selection of velocities at the breakpoint, or absolute concentrations of 2.5 or 4.0 mM; and also comparisons to other protocols In validating any new type of LT protocol, the criterion should be a standard protocol especially when there is adequate research in support.

In conclusion, the disagreement between the proponents and opponents of Conconi's test can largely be explained by the type of LT protocol employed. Neither Conconi's $LT_{discont}$ protocol nor his HR test, provide results similar to that of well-established traditional LT protocols. The discontinuous nature of Conconi's LT protocol, as well as the decreasing stage durations, cause a rightward shift in LT. Therefore, the validity of Conconi's HR deflection must questioned.

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REFERENCES:

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APPENDICIES

APPENDIX A

INFORMED CONSENT FORM

Title: COMPARISON OF TWO LACTATE-THRESHOLD PROTOCOLS IN TRAINED RUNNERS

Investigator: Jason Langley

Address: Exercise Science and Sport Management
College of Education
University of Tennessee
1914 Andy Holt Avenue. / Knoxville, TN 37996

Phone: (865) 974-8768

You are invited to take part in a research study, the purpose of which is to compare two lactate threshold tests for their degree of similarity and accuracy. If you choose to participate, you will be given a brief questionnaire to appraise your general health status.

There will be four different exercise tasks that you will be asked to complete each to be undertaken on a separate day. The first day will have you performing a graded, maximal treadmill test. This involves running, on the treadmill at a constant speed, with the incline gradually increasing in steepness (at one-minute intervals). During this test you will be asked to wear a mouthpiece and a nose clip (to stop you from leaking air through your nose) that will allow us to collect your exhaled air for oxygen content analysis (oxygen uptake values). A heart rate monitor will also be used during this test. On a second day, you will run between 8-12 laps around UT's outdoor 400-meter track, starting out at a relatively slow pace and then gradually increasing your speed every 200 meters. A third day will have you completing a total of six 1200-meter repeats on the outdoor track, at speeds that are both below and above your lactate threshold level (the point at which you begin to accumulate lactate in your bloodstream). You will have 15 minutes of recovery between each repeat. Also, soon after you complete each repeat we will draw a small amount of blood (for a total of 6 ml of blood for the whole test = about 1 teaspoon) from a forearm vein using a basic syringe, in order to measure blood lactate levels. Finally, on a fourth day you will come into the lab and complete a second "lactate threshold test" by running on the treadmill at 8-10 different speeds (3 minutes at each speed). In this test, the 8-10 blood samples will be drawn from a small catheter that will be inserted into an arm vein (which remains in place as you run). The total volume of blood drawn in this test will be about 30 ml of blood, or about 5 teaspoons. The estimated time involvement to complete this entire study is about 4 hours.

Risks and Benefits: There are risks associated with maximal exercise testing, which can include abnormal blood pressure responses, musculo-skeletal injuries, heart rhythm disturbances, and in rare instances heart attack or even death. However, to reduce the likelihood of these events, only subjects who perform regular endurance- type exercise and who have no known history of cardiovascular events or complications will be permitted to participate in this study. There are also some risks associated with the blood sampling process. These include possible internal bleeding around the vein site, and infection. To minimize these risks, only trained persons will perform the blood sampling, and sterile equipment and methods will be used at all times.

The benefits to you include a detailed knowledge of your fitness level, including certain physiological data to help you determine distance-event race paces to maximize your performances. The information that you can provide as a subject in our study will also benefit sports science, specifically in the improved understanding of the accuracy of lactate threshold tests.

Confidentiality: All information pertaining to your participation in this study will be kept confidential. The only persons who will have access to your exercise test results will be the main researcher, Jason Langley and his faculty advisor, Dr. David R. Bassett (Exercise Science Unit, HPER building). The information obtained from these tests will be treated as privileged, and as such it will not be released to any other person, other than the involved researchers, without your consent. This information will be used in research reports or presentations, but your name and any other potentially identifying marks will not be disclosed.

Participation in this research study is entirely voluntary, and you are free to decide whether or not you want to take part, and you are also free to withdraw from this study at any point without any form of penalty.

Please ask any questions that you might have concerning any aspect of this study which you are unclear about, before you sign this form. If you think of any questions at a later time, feel free to call Jason at the phone number noted on the front of this consent form.

Authorization: I, ____________________________ have read the above and decided to participate in the research project described above. My signature also indicates that I have received a copy of this consent form.

Participant's signature ________________________ Date ______________

I hereby certify that I have given to the above individual an explanation of the contemplated study and its risks and potential complications.

Witness' signature ____________________________ Date ________

APPENDIX B

Table 3. Continuous and Discontinuous Lactate Threshold Protocols- Subject 1

Rest	0 575	Weight	165 5		Rest	0.594	Weight·	166	Start RH	80
Temp	22	RH.	59		Start temp	23	Finish temp	25	Finish RH·	79
Continuous					Discontinuous					
Heart rate	Speed-kph	Lactate	Speed-mph		Heart rate	Lactate	Speed-kph			
	13 67	0 622	8 5			0 56	15 07			
	14 47	0 553	9 0			1 07	16 57			
	15 28	0 54	9 5			1 66	18 02			
	16 08	0 632	10 0			2 6	19 06			
	16 88	0.838	10 5			4 16	20 11			
	17 69	1 07	11 0			7 23	21.2			
	18 49	1 56	11 5							
	19 30	2 5	12 0							

APPENDIX C

Table 4. Conconi 200 test and VO_{2max} data- Subject 1

Weight	167		
Temp	24	RH	78
Conconi			
Heart rate	Speed	Split	Sum
132	12.71	56.65	56.65
131	12 81	56 2	112 85
137.5	13.80	52.18	165.03
139	13 97	51.53	216 56
143	14.76	48.79	265.35
145 5	14.87	48.41	313 76
148	15.60	46.14	359.90
150	15.78	45.63	405 53
145	15.61	46.11	451 64
151.5	16.17	44.53	496 17
156 5	16.50	43.63	539.80
158	17.40	41.38	581.18
162	17.66	40.76	621.94
165	18.51	38 9	660 84
168	18.76	38.38	699 22
171.5	19 68	36 59	735.81
173	19 98	36 03	771 84
175	20.89	34.46	806.30
178	21.47	33.53	839.83
178.5	22.17	32.47	872 30
180.5	22 96	31 36	903.66
168	18.76	Break point	

Weight	165.4	lbs	75.18	kg	Lactate	
Temp:	22	RH.	60	Speed		mph

Time	Vol	O2	CO2	VO2	ml/kg	VCO2	RER	HR	VO2 max
0.5	53.65	18 52	2 31	1.31	17 42	1 22	0.93		69.1
1.0	64.27	16 24	3.97	3.12	41.50	2.53	0 81		
1.5	75.00	16 29	4 04	3 58	47.62	3.00	0.84		
2 0	80.68	16 35	4.11	3.79	50 41	3.29	0 87		
2.5	80.46	16.35	4.09	3.79	50.41	3 25	0.86		
3.0	86 68	16.40	4.09	4 02	53.47	3 51	0.87		
3.5	85 36	16.30	4 16	4.06	54.00	3.53	0.87		
4 0	86 53	16.21	4.19	4.19	55.73	3.59	0.86		
4.5	94.61	16.39	4.16	4 38	58.26	3.90	0 89		
5.0	99.50	16.50	4.11	4.49	59.72	4.06	0.90		
5.5	98 96	16.44	4.19	4 51	59.99	4.10	0.91		
6.0	101.43	16 41	4.21	4.66	61.98	4.24	0.91		
6 5	109.55	16.50	4 25	4.90	65.18	4.61	0.94		
7.0	11.84	16.50	4 31	4.98	66.24	4 77	0.96		
7.5	118.93	16 63	4 26	5 11	67.97	5.02	0.98		
8.0	123 06	16 69	4 29	5 19	69.03	5.24	1.01		

APPENDIX D

Table 5. Continuous and Discontinuous Lactate Threshold Protocols- Subject 2

Rest	0.786	Weight	144 5		Rest	0.559	Weight:	146	Start RH	90
Temp	23 5	RH·	59		Start temp·	21	Finish temp:	28	Finish RH	69
Continuous					Discontinuous					
Heart rate	Speed-kph	Lactate	Speed-mph		Heart rate	Lactate	Speed-kph			
	12 86	0 804	8 0			0.748	13.38			
	13.67	0.71	8.5			1.66	15 27			
	14 47	0 732	9 0			2 28	16 76			
	15 28	0 914	9 5			2.63	17 71			
	16 08	1 43	10 0			4.18	18 68			
	16 88	2 25	10.5			6 94	19.37			
	17 69	2.68	11 0							
	18 49	3 18	11 5							
	19 30	5 32	12.0							

APPENDIX E

Table 6. Conconi Test and $\dot{V}O_2$ data- Subject 2

Weight	145 5		
Temp	25	RH	66
Conconi			
Heart rate	Speed	Split	Sum
152	11 58	62 15	62 15
153 5	12 72	56 61	118 76
158	13 13	54 85	173 61
157 5	13.56	53 09	226 70
164.5	14 56	49.46	276 16
173	15 37	46 85	323 01
171.5	15 81	45 54	368 55
174	16 35	44 05	412 60
179.5	16 78	42 92	455 52
182	17 58	40 96	496 48
183	18 04	39 92	536.40
185 5	18.43	39 06	575 46
189	18 88	38 14	613 60
190	19 26	37 39	650 99
191	19.45	37 01	688 00
192	20 41	35 28	723 28
191 5	21 80	33 03	756 31
180	16 78	Break point	

148	lbs	67 3	kg	Lactate		
23	RH	58	Speed	10		

Time	Vol	O2	CO2	VO2	ml/kg	VCO2	RER	HR	VO2 max
0 5	41 40	20 63	0.43	0.10	1 49	0.15	1 50		68.38
1.0	47 87	17 19	3 37	1 83	27 20	1.58	0 86		
1 5	94.65	16 84	3.79	3 94	58 57	3 55	0 90		
2 0	94 03	16 88	3 74	3 87	57.53	3 49	0 90		
2 5	94 96	16 89	3 70	3 91	58 12	3 48	0 89		
3 0	94 40	16 80	3 73	3 99	59 31	3 49	0.87		
3 5	100 00	16 82	3 74	4.19	62 28	3 70	0 88		
4 0	107 00	16 98	3 63	4 32	64.22	3 84	0 89		
4 5	104.68	16 86	3 76	4 33	64.36	3.91	0 90		
5 0	116 61	17 12	3 61	4 50	66.89	4 16	0 92		
5 5	119 87	17 21	3 59	4 50	66 89	4 26	0 95		
6 0	121 78	17 17	3 67	4.60	68 38	4 42	0 96		

APPENDIX F

Table 7. Continuous and Discontinuous Lactate Threshold Protocols- Subject 3

Rest	1 41	Weight	171 5		Rest	1 2	Weight:	170 5	Start RH	92
Temp	21 5	RH	59 5		Start temp·	15	Finish temp.	24	Finish RH	70
Continuous					Discontinuous					
Heart rate	Speed-kph	Lactate	Speed-mph		Heart rate	Lactate	Speed-kph			
	9 65	1.53	6 0			1 84	12			
	10 45	1 51	6 5			3.26	13 5			
	11 26	1 77	7 0			5 17	15			
	12 06	2.03	7.5			6.2	16			
	12 86	2 55	8 0			10 1	17			
	13 67	3 1	8 5							
	14 47	3 85	9 0							
	15 28	5 74	9 5							
	16 08	8 54	10 0							

APPENDIX G

Table 8. Conconi Test and $\dot{V}O_{2max}$ Data- Subject 3

Weight	169				
Temp·	24	RH	88		
Conconi					
Heart rate	Speed	Split	Sum	Speed	Split
136 5	11.69	61.57	61 57		
140	11.48	62 72	124 29		
149	12 51	57 56	181 85		
152.5	12 47	57 73	239 58		
156	13 16	54 73	294 31		
160 5	13.43	53 62	347.93		
165 5	14 28	50 43	398 36		
167 5	14 43	49 9	448 26		
170.5	14.96	48 13	496.39		
175 5	15 43	46 67	543 06		
178	15 94	45 16	588 22		
180	16 21	44 43	632 65		
184	16 74	43 01	675 66		
187	17 40	41 37	717 03		
190 5	18 81	38 27	755 30		
176	15 43	Break point			

Weight	170 5	lbs	77.5	kg	Lactate		
Temp	21	RH	60	Speed			

Time	Vol	O2	CO2	VO2	ml/kg	VCO2	RER	HR	VO2 max
0 5	87 55	16.93	3 64	3 58	46 19	3 16	0 88		62 32
1 0	81.83	16 82	3 71	3 45	44 52	3 00	0 87		
1 5	86 12	16 90	3 64	3 54	45.68	3.11	0 88		
2 0	87 86	16 90	3 64	3 62	46.71	3 16	0.87		
2.5	88 03	16 98	3.67	3 54	45 68	3 20	0 90		
3 0	92 96	16 85	3 75	3 87	49.94	3 45	0 89		
3 5	99.90	16 94	3 66	4 08	52 65	3 62	0.89		
4 0	104.65	17.08	3.70	4 07	52.52	3.83	0 94		
4 5	108.28	17 10	3 69	4 17	53 81	3 96	0 95		
5 0	118.37	17.22	3 65	4 41	56.90	4 27	0 97		
5 5	120.90	17 33	3 63	4.34	56.00	4 35	1 00		
6 0	129 37	17.39	3 65	4 53	58 45	4 67	1.03		
6 5	124.18	17.28	3 78	4 49	57 94	4 65	1 04		
7 0	132 44	17 28	3 81	4 77	61.55	5.00	1.05		
7 5	135 43	17 39	3.82	4 69	60 52	5 13	1 09		
8.0	139 07	17.37	3 84	4.83	62.32	5 30	1 10		

APPENDIX H

Table 9. Continuous and Discontinuous Lactate Threshold Protocols- Subject 4

Rest	1	Weight	148		Rest	1 01	Weight	148	Start RH	38
Temp.	21	RH:	67		Start temp·	27	Finish temp:	29	Finish RH·	37
Continuous					Discontinuous					
Heart rate	Speed-kph	Lactate	Speed-mph		Heart rate	Lactate	Speed-kph			
118	9.65	1.435	6 0		135	0 978	11 9			
120	10 45	1.345	6 5		151	0 978	13.3			
124	11 26	1 08	7 0		163	1 42	15			
133	12 06	1.245	7 5		181	5 1	17 8			
138	12.86	1 275	8 0		184	3.87	18 1			
146	13 67	1 43	8 5		190	10.65	19 8			
155	14 47	1 6	9 0							
161	15 28	1 9	9 5							
166	16 08	2.785	10 0							
174	16.88	3.645	10 5							
178	17 69	5 15	11 0							

APPENDIX I

Table 10. Conconi Test and $\dot{V}O_{2max}$ Data- Subject 4

Weight	146		
Temp	23	RH	75
Conconi			
Heart rate	Speed	Split	Sum
144	13 26	54 31	54.31
154	13.86	51 95	106.26
154 5	13 96	51.56	157 82
159	14 47	49 77	207 59
161	14 86	48 45	256 04
166	15 70	45 85	301 89
169	15 91	45 26	347 15
174	16 14	44 61	391 76
176 5	16 89	42.64	434 40
179 6	17 53	41 08	475 48
178 5	17 58	40 96	516 44
181	17 84	40 35	556 79
184	18 36	39 22	596 01
186 5	19 17	37 55	633 56
188.5	19 32	37.26	670 82
192 5	20 63	34 9	705 72
176 5	16.89	Break point	

Weight	147 5	lbs	67.05	kg		Lactate	7 86
Temp.	20	RH	45	Speed		9 5	
Age	24						

Time	Vol	O2	CO2	VO2	ml/kg	VCO2	RER	HR	VO2 max
1 0	50 32	15 47	5 02	2 82	42 06	2.51	0.89	143	66 82
2 0	57 72	15 60	5 21	3.11	46 39	2 99	0.96	154	
3 0	62.05	15 50	5 34	3 40	50 71	3 29	0 97	159	
4 0	66.22	15 61	5 34	3 54	52 80	3 52	0.99	167	
5 0	65 39	15 22	5 64	3.76	56.08	3 67	0 98	169	
6 0	81 25	15 83	5 33	4 11	61 30	4 30	1 05	177	
7 0	90 45	16 17	5 12	4 24	63 24	4.60	1 08	182	
8 0	101.22	16 47	4.91	4 41	65 78	4 94	1.12	186	
9 0	113 13	16 85	4 62	4 48	66 82	5 19	1 16	190	
10.0	116 09	16 96	4 56	4 45	66 37	5 26	1.18	193	
11 0	112 31	16 93	4 68	4 32	64 43	5 22	1 21	194	

APPENDIX J

Table 11. Continuous and Discontinuous Lactate Threshold- Subject 5

Rest	0 76	Weight	172		Rest	0.66	Weight	173	Start RH.	35
Temp	16	RH	45		Start temp:	24	Finish temp.	25	Finish RH·	31
Continuous					Discontinuous					
Heart rate	Speed-kph	Lactate	Speed-mph		Heart rate	Lactate	Speed-kph			
127	9 65	0.873	6 0		119	0.768	10 1			
133	10 45	1 13	6.5		137	0.995	11 6			
139	11 26	1 09	7 0		143	1 42	12 9			
144	12 06	1 01	7 5		161	5 2	15 7			
148	12.86	1 26	8 0		165	9.43	16 6			
154	13 67	1 79	8 5		170	11 95	17 1			
162	14 47	2 26	9 0							
170	15 28	3 43	9 5							

APPENDIX K

Table 12. Conconi Test and $\dot{V}O_{2max}$ Data- Subject 5

Weight	174	lbs	
Temp.	22	RH	67
Conconi			
Heart rate	Speed	Split	Sum
127 5	10 08	71 43	71 43
127 5	10 13	71 05	142 48
133	11 26	63 92	206 40
135	11.43	63	269 40
139.5	12 03	59.87	329 27
138	12 06	59 68	388 95
140 5	13 07	55 07	444 02
145 5	13 22	54 48	498 50
148	13.65	52 74	551.24
151	14 30	50 36	601 60
154 5	15 09	47 72	649 32
156 5	15 21	47 34	696 66
158 5	15.59	46 19	742 85
159	15 91	45 26	788.11
162	16.44	43 8	831 91
156 5	15 21	Break point	

Weight	172	lbs	78 18	kg		Lactate	8 54
Temp	20	RH	30	Speed		9	
Age	41						

Time	Vol	O2	CO2	VO2	ml/kg	VCO2	RER	HR	RR	VO2 max
1 0	60.89	15 62	4 92	3 31	42 34	2 98	0 90	141		52 57
2 0	72 41	16 15	4.84	3.47	44.38	3.48	1.00	154		
3 0	74 88	16 17	4 9	3 56	45 53	3.64	1.02	156		
4 0	81 49	16 32	4 81	3 73	47.71	3 90	1.05	159		
5 0	90 02	16 48	4 77	3 95	50 52	4 26	1.08	163		
6 0	98 24	16 73	4 64	4 03	51 55	4 53	1.12	166		
7 0	104 96	16.89	4 6	4.11	52 57	4 80	1 17	169		

APPENDIX L

Table 13. Continuous and Discontinuous Lactate Threshold Protocols- Subject 6

Rest	3	Weight	138		Rest	1 625	Weight	140	Start RH.	73
Temp	20	RH	70		Start temp	23	Finish temp	25	Finish RH	67
Continuous					Discontinuous					
Heart rate	Speed-kph	Lactate	Speed-mph		Heart rate	Lactate	Speed-kph			
150	9 65	2 54	6 0		146	2 24	10 6			
157	10 45	2 12	6 5		162	2.31	11 5			
164	11 26	2 35	7 0		176	2.735	13 2			
173	12 06	2 9	7 5		187	5 09	15 5			
182	12 86	4 12	8 0		195	8 045	16 7			
185	13.67	5 18	8.5		199	12 1	18.1			
190	14 47	6 79	9 0							
196	15 28	8 77	9 5							
199	16 08	10 85	10.0							

APPENDIX M

Table 14. Conconi Test and $\dot{V}O_{2max}$ Data-. Subject 6

Weight	140		
Temp:	26	RH·	45
Conconi			
Heart rate	Speed	Split	Sum
162	13.87	51.9	51.90
166	12 70	56.71	108 61
174	14.40	50	158.61
180.5	14.79	48 68	207 29
182	14.92	48 25	255 54
186	15.26	47 17	302 71
185 5	15.98	45 07	347.78
188 5	16 70	43.11	390 89
190	16 97	42 44	433.33
192.5	17 42	41 33	474 66
194	17.72	40.64	515.30
195	18 48	38 96	554 26
197 5	18 54	38 84	593.10
186	15 26	Break point	

Weight	138	lbs	62.73	kg		Lactate	8 69
Temp	21	RH·	55	Speed		8.3	
Age	26						

Time	Vol	O2	CO2	VO2	ml/kg	VCO2	RER	HR	VO2 max
1 0	59 86	16.10	4 32	2.99	47.67	2 57	0.86	163	67.75
2 0	68 90	16 36	4.38	3 19	50.86	3.00	0 94	173	
3 0	75.55	16 59	4.31	3.30	52.61	3.23	0 98	177	
4.0	80 74	16 65	4 36	3.46	55.16	3 49	1 01	180	
5 0	85 25	16 68	4 39	3.61	57 55	3 72	1.03	183	
6 0	96 56	16.94	4 26	3 81	60 74	4 09	1.07	187	
7 0	103.09	17 04	4 21	3.94	62.81	4.31	1.09	189	
8 0	111.84	17.18	4 13	4 11	65 52	4 58	1 11	193	
9 0	122 24	17 38	4.01	4.22	67.28	4.86	1 15	195	
10.0	126.91	17.47	3.96	4.25	67 75	4 99	1 17	198	

APPENDIX N

Table 15. Continuous and Discontinuous Lactate Threshold Protocols- Subject 7

Rest	1.54	Weight	155		Rest	2 61	Weight.	155	Start RH:
Temp·	23	RH·	60		Start temp	22	Finish temp.	23	Finish RH.
Continuous					Discontinuous				
Heart rate	Speed-kph	Lactate	Speed-mph		Heart rate	Lactate	Speed-kph		
115	12.06	0.911	7 5		133	0 973	14		
121	12 86	0 539	8.0		145	1 065	15 4		
126	13 67	0.34	8 5		155	1	16.7		
134	14 47	0 28	9 0		177	3 56	19 5		
142	15 28	0 626	9 5		182	7.135	20 5		
149	16.08	0 41	10.0						
154	16 88	1 17	10.5						
163	17.69	1.53	11 0						
170	18 49	1 815	11 5						
178	19 30	3 22	12 0						

APPENDIX O

Table 16. Conconi Test and $\dot{V}O_{2max}$ Data- Subject 7

Weight	155		
Temp:	17	RH·	65
Conconi			
Heart rate	Speed	Split	Sum
137	13 03	55.26	55 26
144 5	13 75	52 38	107 64
144.5	14 43	49 89	157 53
146 5	15 25	47 2	204 73
149	15 85	45 43	250 16
151 5	16 97	42 42	292 58
158 5	17 06	42 21	334.79
160 5	17 95	40 12	374 91
160	17 64	40.81	415 72
161	18 02	39 96	455 68
166	18 96	37 97	493 65
169	19 17	37 55	531 20
172 5	19.32	37 26	568 46
171	19 59	36 75	605 21
174	19 65	36 65	641.86
175 5	19 92	36 14	678.00
174 5	20 74	34 72	712 72
169	19.17	Breakpoint	

Weight	155	lbs	70 5	kg	Lactate	
Temp·	24	RH·	50	Speed		

Age· 27 Height ______

Time	Vol	O2	CO2	VO2	ml/kg	VCO2	RER	HR	VO2 max
1 0	73 78	16 07	4 52	3 67	52 09	3 31	0.90	149	67 42
2 0	83 07	16 29	4.6	3 88	55 07	3 79	0 98	159	
3.0	87 97	16.25	4 68	4 13	58 62	4.09	0 99	163	
4 0	96 49	16 44	4 63	4 32	61 32	4.44	1 03	168	
5 0	101 90	16.45	4 69	4.53	64.30	4.74	1.05	173	
6 0	106 32	16 52	4.73	4.62	65 57	5 00	1 08	176	
7 0	117 08	16 78	4 58	4.75	67 42	5.32	1.12	179	
8 0	111.92	16 87	4 62	4 40	62.45	5.14	1 17	181	

APPENDIX P

Table 17. Continuous and Discontinuous Lactate Threshold Protocols- Subject 8

Rest	0 687	Weight	187		Rest	2 99	Weight	188	Start RH·	82
Temp	23	RH	55		Start temp	22	Finish temp.	23	Finish RH.	86
Continuous					Discontinuous					
Heart rate	Speed-kph	Lactate	Speed-mph		Heart rate	Lactate	Speed-kph			
121	9 65	0.871	6 0		124	0 929	11 29			
125	10 45	0.74	6.5		148	1 18	12.74			
132	11 26	0 623	7 0		162	1 375	14 2			
136	12 06	0.627	7 5		176	5 17	16 94			
151	12 86	0 602	8.0		176	5 4	17 65			
155	13.67	0.758	8 5							
160	14 47	1 02	9.0							
165	15 28	1 62	9 5							
173	16 08	2 59	10 0							
177	16 88	4 34	10 5							
181	17 69	6 835	11 0							

APPENDIX Q

Table 18. Conconi Test and $\dot{V}O_{2max}$ Data- Subject 8

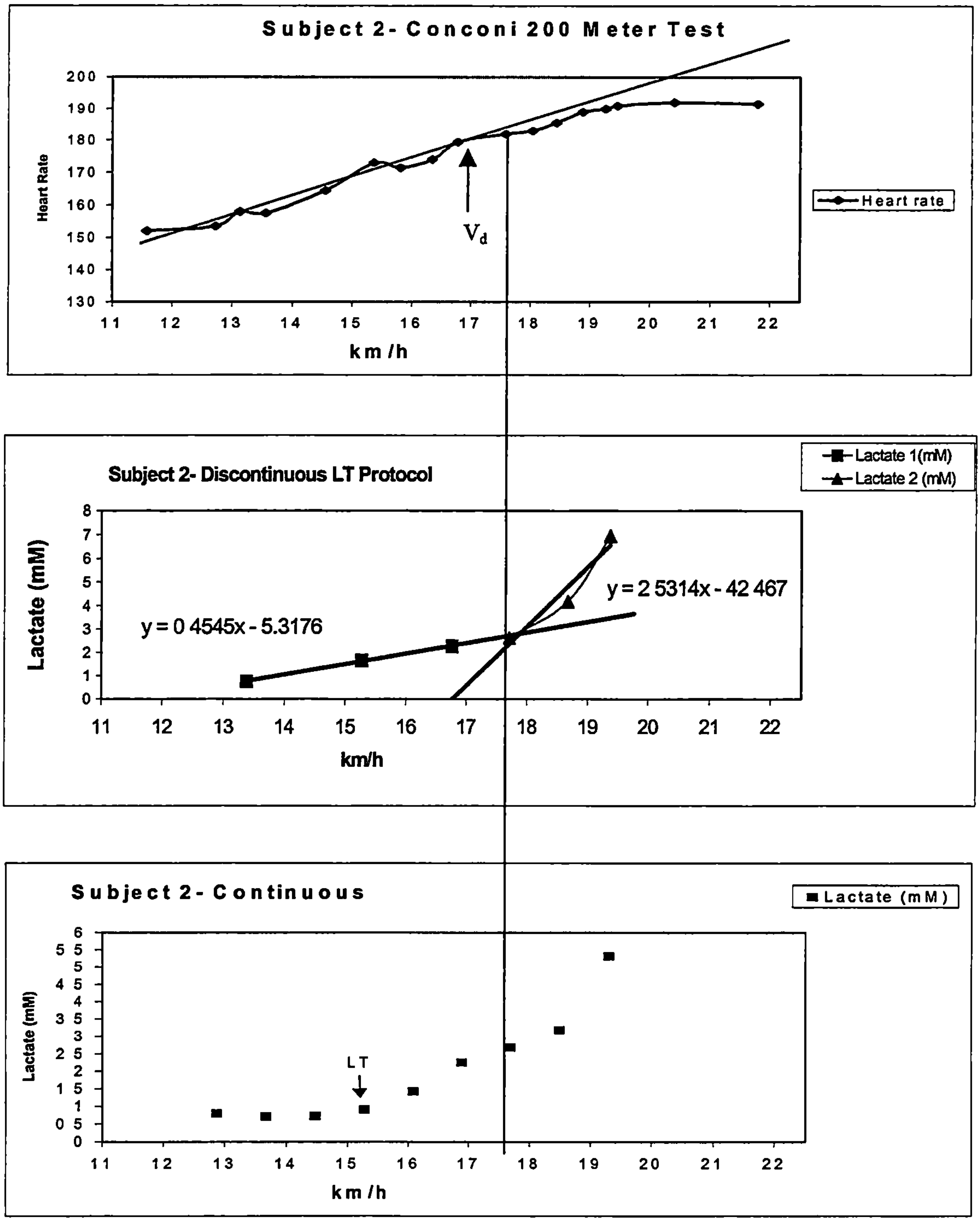
Weight	189		
Temp	23	RH	66
Conconi			
Heart rate	Speed	Split	Sum
131 5	12.29	58 57	58 57
143	12.71	56 67	115 24
147	13.25	54 35	169 59
149	13.75	52 36	221 95
156 5	14.81	48 622	270 57
159	14.98	48 06	318 63
162 5	16 01	44 97	363 60
168 5	15 99	45 04	408 64
169	16 26	44 29	452.93
171	16 92	42 55	495 48
175	17 16	41 96	537.44
178	17 17	41.93	579.37
178	17 60	40.91	620 28
180	17 85	40 33	660 61
179.5	18 33	39 29	699.90
177	18 59	38.73	738 63
169	16 26	Breakpoint	

Weight	187	lbs	85	kg		Lactate	10 1
Temp.	24	RH.	50	Speed		9	
Age:	36	Height	190				

Time	Vol	O2	CO2	VO2	ml/kg	VCO2	RER	HR	VO2 max
1 0	61.43	16 06	4.55	3 06	36 00	2 78	0.91	156	54 5
2 0	72 26	16.22	4 58	3.44	40 47	3 29	0 96	165	
3.0	79.23	16 24	4.65	3 74	44 00	3.66	0.98	169	
4 0	81.10	16 17	4 73	3 88	45 65	3.81	0 98	173	
5.0	96.94	16 50	4 57	4 28	50.35	4.40	1 03	175	
6.0	111 06	16.91	4 33	4.40	51.76	4 77	1 08	179	
7.0	122 95	17 07	4.32	4.63	54 47	5 28	1 14	182	
8 0	139.31	17 46	4 08	4 63	54 47	5 65	1.22	186	

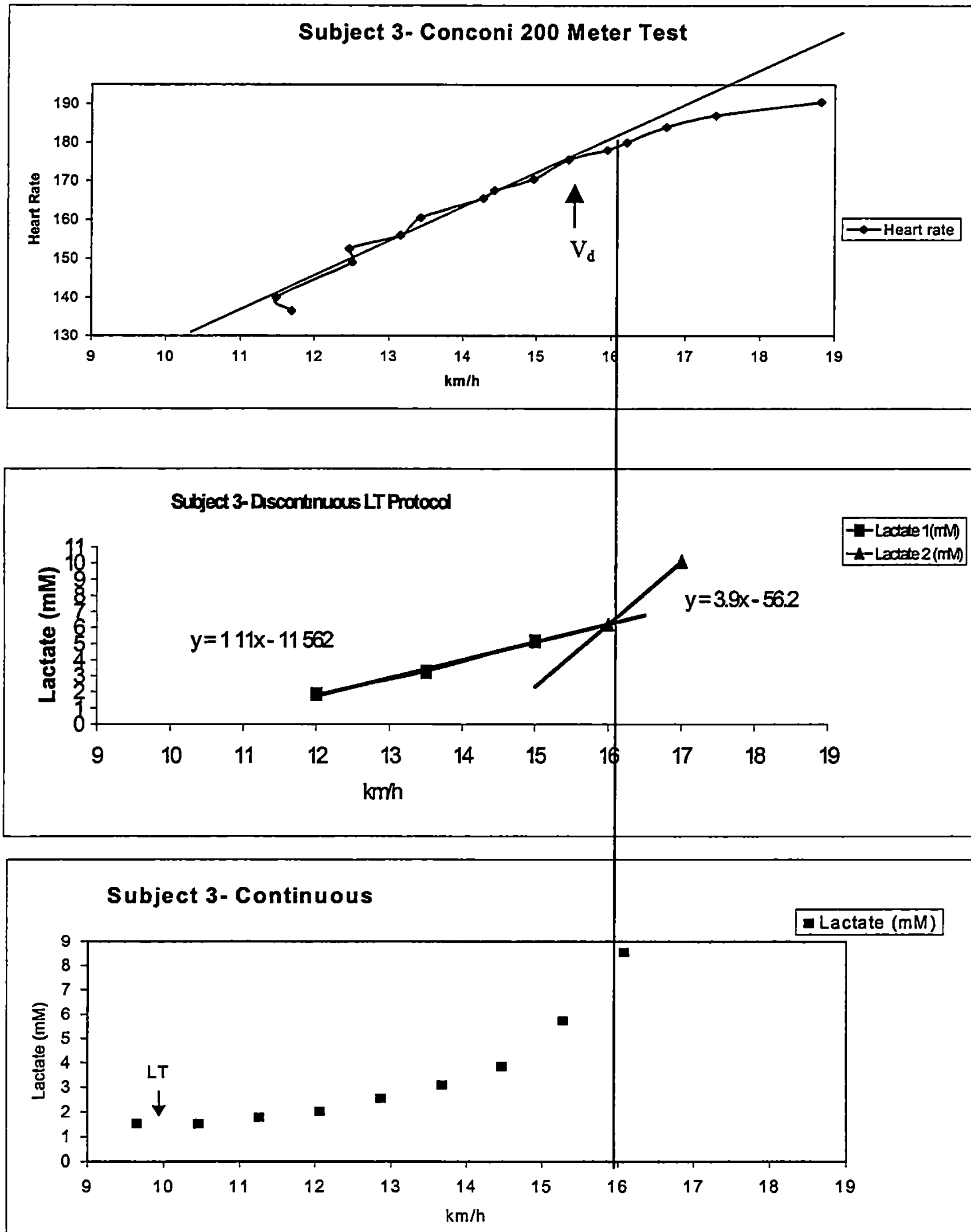
APPENDIX R

Figure 12. V_d, $LT_{discont}$, and LT_{cont} Data- Subject 2



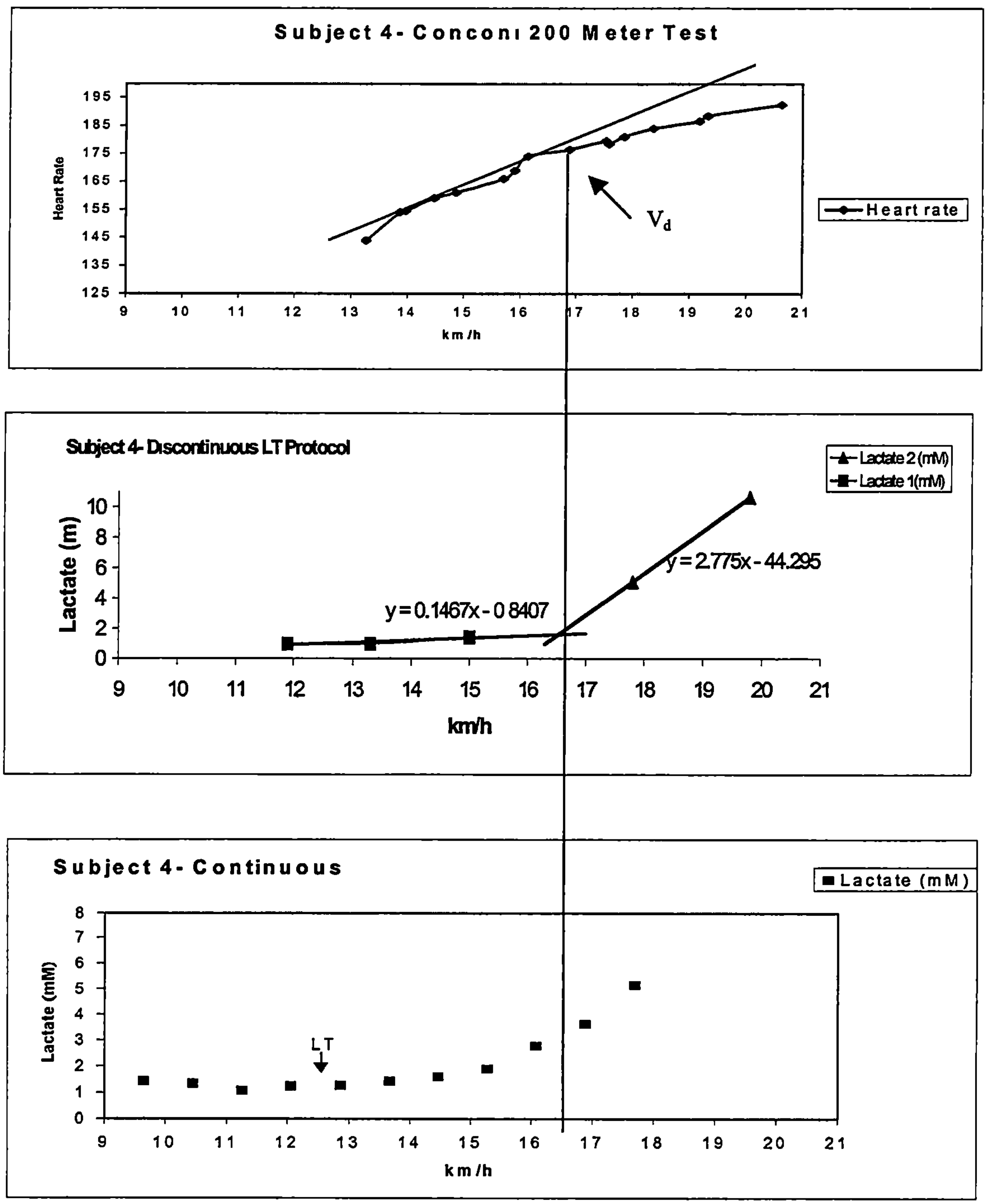
APPENDIX S

Figure 13. V_d, $LT_{discont}$, LT_{cont} data- Subject 3



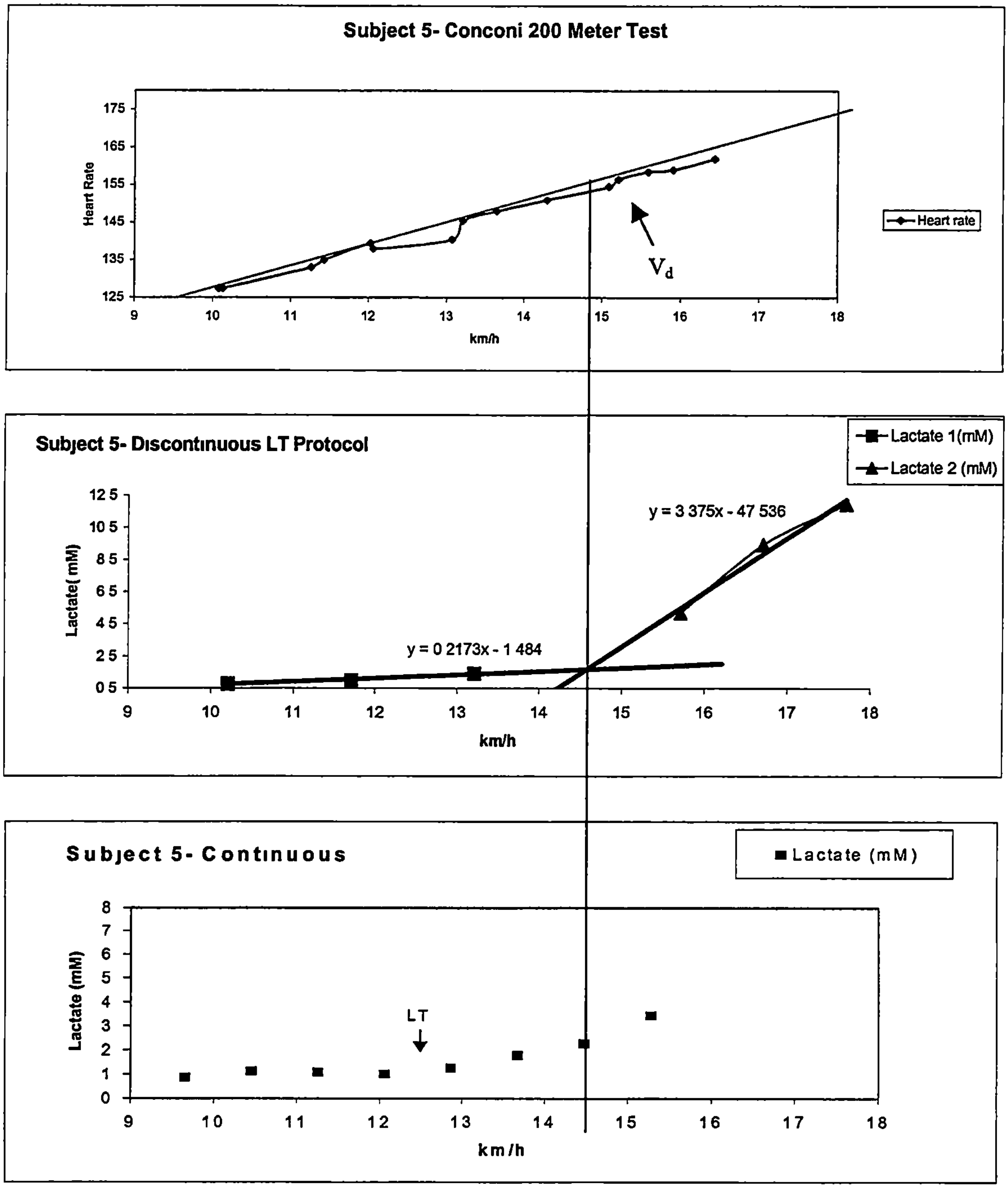
APPENDIX T

Figure 14. V_d, $LT_{discont}$, LT_{cont} data- Subject 4



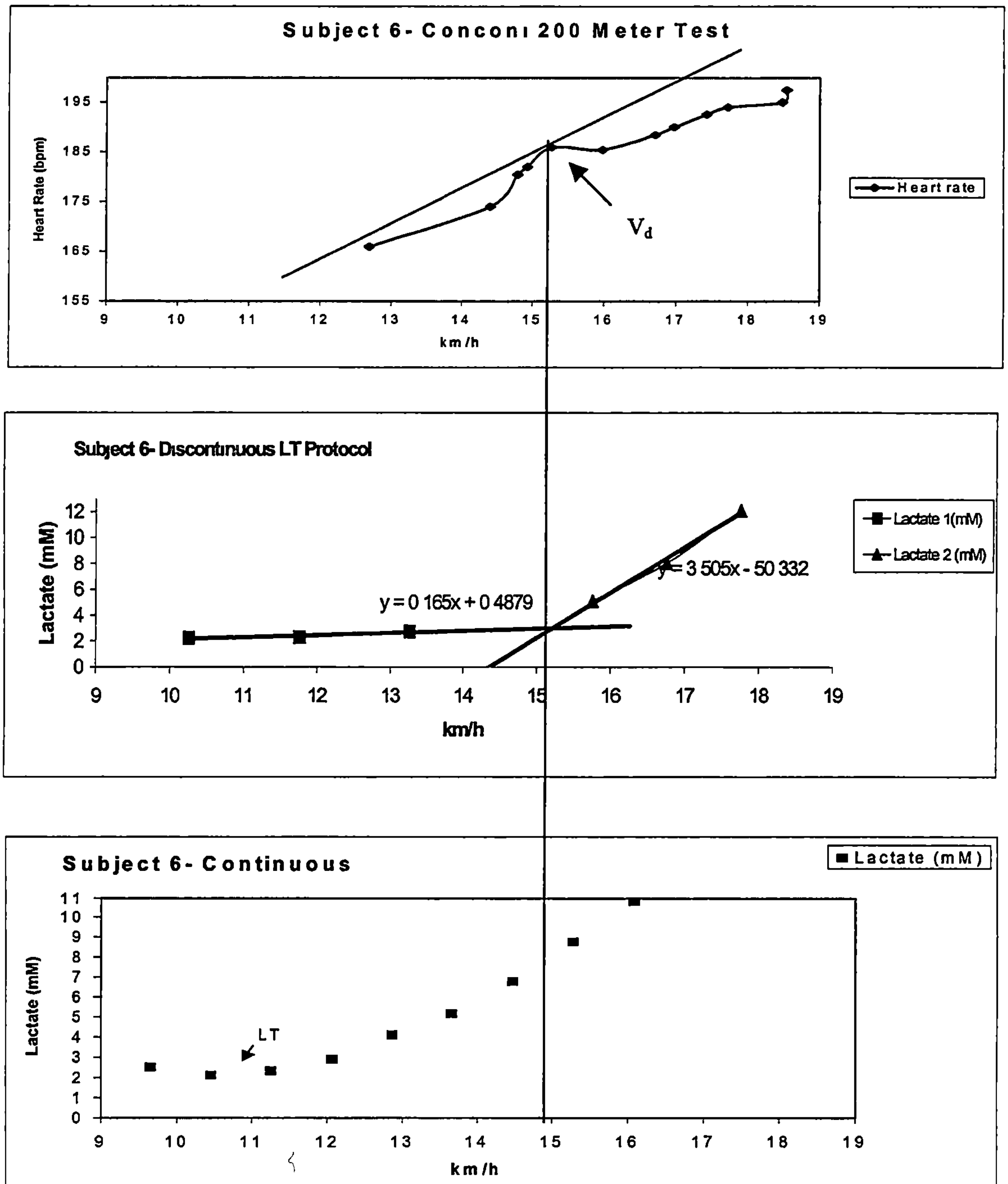
APPENDIX U

Figure 15. V_d, $LT_{discont}$, LT_{cont} data- Subject 5



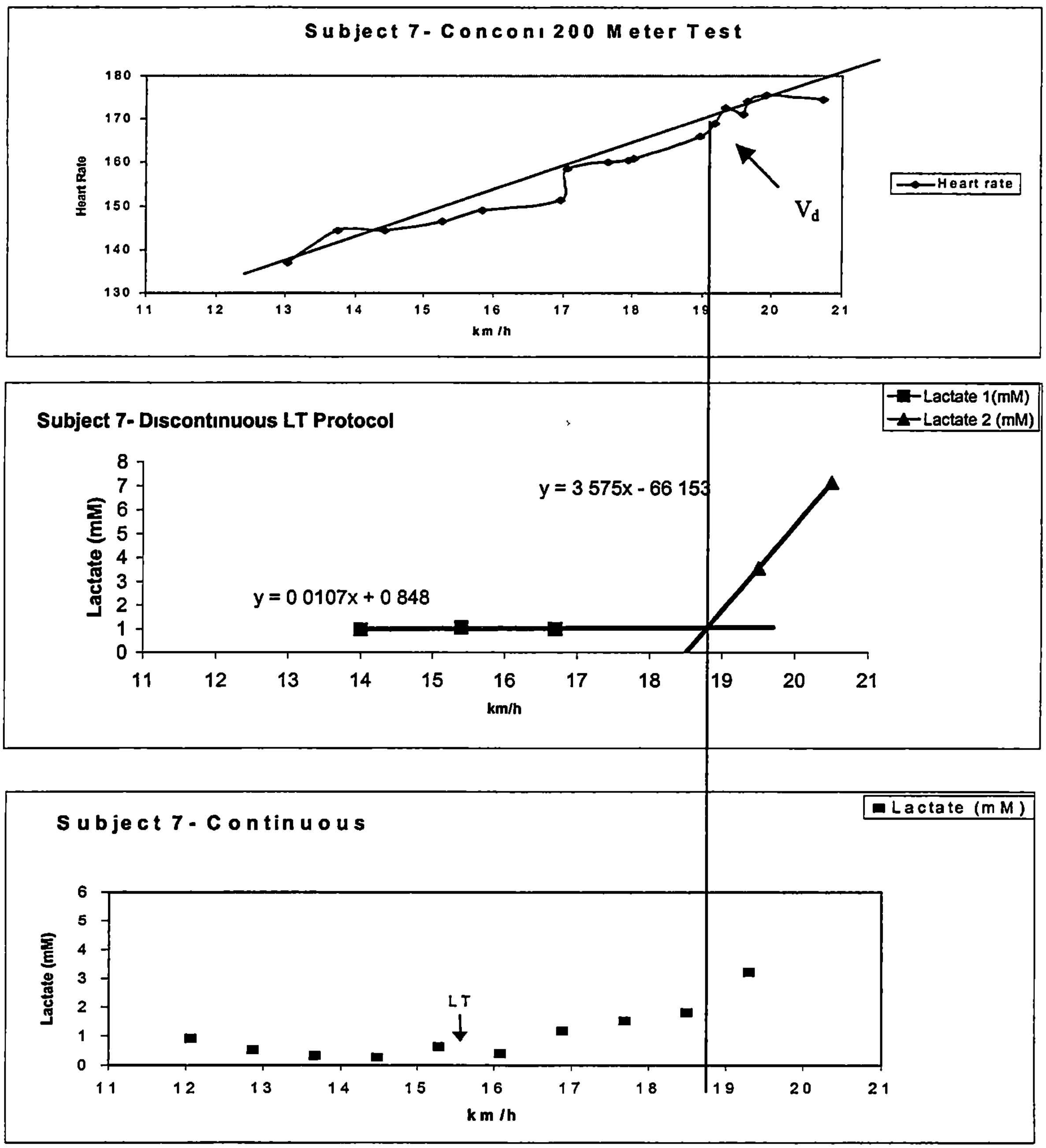
APPENDIX V

Figure 16. V_d, $LT_{discont}$, LT_{cont} data- Subject 6



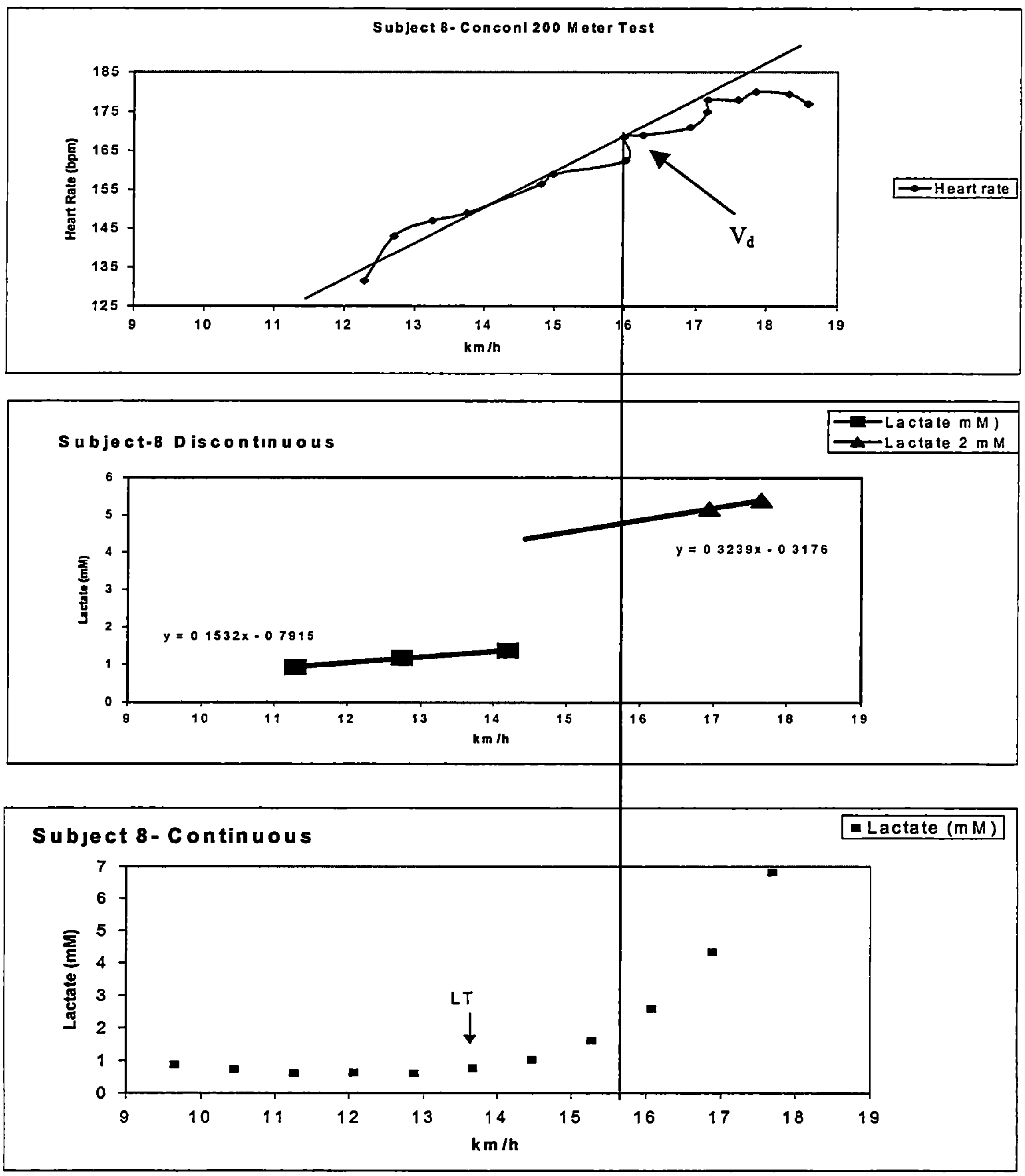
APPENDIX W

Figure 17. V_d, $LT_{discont}$, LT_{cont} data- Subject 7



APPENDIX X

Figure 18. V_d, $LT_{discont}$, LT_{cont} data- Subject 8



VITA

Jason Glenn Langley was born in Wichita, Kansas on February 26, 1975. He then moved to Racine, Wisconsin at the age of 4. He attended Schulte elementary school, Mitchell middle school and JI Case High School, where he graduated in 1993. While in high school Jason played varsity baseball and volleyball, collecting two state volleyball championships. In the fall of 1993 he entered Winona State University and in May of 1998 he earned a Bachelor of Science in Corporate Wellness and Adult Fitness. The following fall he entered the University of Tennessee-Knoxville and received his Master of Science degree in Human Performance and Sport Studies, in August of 2000. During his time at Tennessee he had the privilege to be involved in several research studies, and was a Graduate Teaching Associate during his final year. He also began to run during his final year and completed two half-marathons. His future plans are to complete his education at West Virginia University by earning a Doctorate of Philosophy. This will hopefully lead him to an academic position at the college or university level as professor of exercise science and coach of an athletic team.