

ABSTRACT

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The equations examined were developed by Weltman et al. (1987) and presented in "Predictions of lactate threshold and fixed blood lactate concentrations from a 3200-m running performance in male runners". In the present study, 27 trained male runners ($x = 22.5$ yrs) completed a horizontal treadmill test for the determination of lactate threshold (LT), fixed blood lactate concentrations (FBLC), and peak values. At the end of each 3 min stage, blood was sampled from a finger tip puncture and later analyzed for blood lactate concentration (BLa) using a Yellow Springs Instruments 23L lactate analyzer. Velocity was increased $13.4 \text{ m} \cdot \text{min}^{-1}$ each stage. Subjects also ran a 3200 m time trial (RT) [$x = 10:18$]. Oxygen consumptions (VO_2) at LT, FBLC of 2.0, 2.5, and $4.0 \text{ mmol} \cdot \text{l}^{-1}$ were 58.5, 58.4, 60.7, and 65.1 corresponding to 84.5%, 84.4%, 87.8%, and 93.9% of $\text{VO}_{2\text{peak}}$. Mean $\text{VO}_{2\text{peak}}$ was $69.3 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Velocities (VEL) at LT, 2.0, 2.5, $4.0 \text{ mmol} \cdot \text{l}^{-1}$, and peak were 261.1, 261.4, 272.1, 290.2, and $321.3 \text{ m} \cdot \text{min}^{-1}$ corresponding to 81.3%, 81.4%, 84.7%, and 90.4% of VEL_{peak} . Significant ($p \leq .01$) correlations were observed between 3200 m time and VO_2 at LT (VO_2) [$r = -.58$] and VO_2 at $4.0 \text{ mmol} \cdot \text{l}^{-1}$ ($\text{VO}_2\text{-}4.0$) [$r = -.40$]. All correlations were significant ($p \leq .01$) between 3200 m time and VEL associated with LT, FBLC of 2.0, 2.5, $4.0 \text{ mmol} \cdot \text{l}^{-1}$, and peak ($r = -.69, -.50, -.58, -.62$, and $-.65$, respectively). No significant ($p \geq .05$) differences were observed between predicted and actual scores for $\text{VO}_2\text{-LT}$, $\text{VO}_{2\text{peak}}$, and VEL at LT (VEL-LT). A small difference ($p \leq .05$) was observed for VEL at $4.0 \text{ mmol} \cdot \text{l}^{-1}$. Significant ($p \leq .01$ to $p \leq .001$) differences were observed between predicted and actual scores for all other variables. The equations to predict $\text{VO}_2\text{-LT}$, $\text{VO}_2\text{-FBLC}$, and $\text{VO}_{2\text{peak}}$ were accurate and therefore valid for prediction and exercise prescription. In contrast, the SEE values observed for equations to predict VEL-BLa parameters were not within acceptable limits. Therefore, the present study did not find the equations to predict VEL-LT, and VEL-FBLC valid using the present methods. However, the equation to predict VEL_{peak} may be appropriate for prediction and exercise prescription.

VALIDATION OF EQUATIONS TO PREDICT LACTATE THRESHOLD,
FIXED BLOOD LACTATE CONCENTRATIONS, AND PEAK VALUES
FROM A 3200 METER PERFORMANCE TIME

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THESIS FINAL ORAL DEFENSE FORM

Candidate: Vern Joseph La Mere

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science, Physical Education - Human Performance

The candidate has successfully completed his final oral examination.

NKBatts
Thesis Committee Chairperson Signature

11-19-91
Date

William Floyd
Thesis Committee Member Signature

11/18/91
Date

J. C. F.
Thesis Committee Member Signature

11/19/91
Date

This thesis is approved by the College of Health, Physical Education, and Recreation.

Harold Tynen
Associate Dean, College of Health,
Physical Education, and Recreation

12-18-91
Date

Robert Krjewski
Dean of UW-L Graduate Studies

12-20-91
Date

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CHAPTER I

INTRODUCTION

Success in endurance sports such as running has been shown to be positively associated with a number of physiological attributes. These include VO_{2max} , (Costill, 1967; Costill, Thomason, & Roberts, 1973), running economy (Conley & Krahenbuhl, 1980; Daniels, 1985), muscle fiber type (Costill, Fink, & Pollock, 1976; Foster, Costill, Daniels, & Fink, 1978), body composition (Wilmore & Brown, 1974), blood lactate concentrations (BLa) and anaerobic threshold (Conconi, Ferrari, Ziglio, Doroggetti, & Codeca, 1982; Kohrt, O'Conner, & Skinner, 1989; Tanaka et al., 1983). However, it has been suggested that the fractional use oxygen associated with the anaerobic threshold (VO_{2-AT}) may be the best the single best determinant of endurance performance (Kumagai, Tanaka, Matsuura, Hirakoba, & Asano, 1982; Tanaka, & Matsuura, 1984; Yoshida, Chida, Masahiko, & Suda, 1987). To confirm this, performances of endurance athletes have been shown to improve with positive changes in VO_{2-AT} (Acevedo & Goldfarb, 1989; Denis, Fouquet, Poty, Geyssant, & Lacour, 1982; Kohrt et al., 1989; Tanaka & Matsuura, 1984).

Traditionally, the most widely accepted measurement of cardiorespiratory fitness has been maximal oxygen consumption (VO_{2max}) (American College of Sports Medicine, 1990). Its correlations with endurance performance however, range from .57 (Kumagai et al., 1982), to .91 (Farrell, Wilmore, Coyle, Billing, & Costill, 1979).

In contrast to this, BLA concentrations measured during exercise have been shown to be highly correlated with success in endurance performance, consistently ranging from .84 (Kumagai et al., 1982) to .99 (Fohrenbach, Mader, & Hollmann, 1987). In addition, individuals with similar VO_{2max} values often perform differently, and their performances have been shown to improve with no increase in VO_{2max} (Denis et al., 1982; Henritze, Weltman, Schurrer, & Barlow, 1985).

This evidence suggests that BLA parameters may be valid measures of fitness (Acevedo & Goldfarb, 1989; Tanaka et al., 1983; Yoshida et al., 1987). In these and other reports, significant relationships have been observed among running velocity and VO_2 associated with BLA concentrations (Tanaka, 1986; Henritze et al., 1985; Weltman et al., 1987; Weltman et al., 1989; Weltman, Seip et al., 1990).

For the endurance athlete, training at the proper intensity is of primary concern. Likewise, for all individuals who exercise, the American College of Sports Medicine (1990) has stressed the importance of proper intensity for exercise. Studies suggest that using relative intensities based on heart rate (HR) and/or VO_2 may not provide the optimal training stimulus across individuals. Therefore, their use in exercise prescription may need to be reevaluated (Dwyer & Bybee, 1983; Katch, Weltman, Sady, & Freedson, 1978; Weltman et al., 1987; Weltman, Snead, Seip et al., 1990). These researchers suggest that BLA concentrations associated with certain exercise intensities more closely identify optimal levels of physiological stress for endurance training. Therefore, it has been proposed that training intensity be prescribed according to VO_2 , HR, and/or velocity associated with fixed BLA

concentrations, since all of these variables correlate highly with BLA values during exercise (Henritze et al., 1985; Kindermann, Simon, & Keul, 1979; Weltman et al., 1987; Weltman, Snead, Seip et al., 1990).

However, the direct measurement of VO_2 and BLA requires expensive and sophisticated laboratory equipment, as well as trained personnel to administer the tests. These limitations make assessment of these performance variables impractical for use in field settings. In response to this, several investigators have developed equations to predict lactate concentrations from performance times of field tests such as the 1500 and 3200 m runs (Tanaka, 1986; Tanaka et al., 1985; Weltman et al., 1987; Weltman et al., 1989; Weltman, Seip et al., 1990). These equations subsequently provide information regarding VO_2 , velocity, and HR that are associated with lactate threshold (LT) and certain fixed blood lactate concentrations (FBLG) which are designated as 2.0 millimole per liter of blood ($\text{mmol}\cdot\text{l}^{-1}$), 2.5 $\text{mmol}\cdot\text{l}^{-1}$, and 4.0 $\text{mmol}\cdot\text{l}^{-1}$ (Weltman et al., 1987). These lactate concentrations have been shown to appear at critical levels of intensity and physiological stress during exercise (Heck, Mader, Hess, Mucke, & Hollmann, 1985; Kindermann et al., 1979; Skinner & McLellan, 1980). The availability of these types of prediction equations makes indirect assessment of lactate simple and practical, providing the endurance athlete or coach with an invaluable tool for identifying optimal training intensities. However, before they can be used with confidence, the accuracy of these equations, including the methodology used to produce them, requires further investigation.

The present study was conducted to provide additional information

and insight into the practical use of these equations, and to assess their value for use with well trained male runners. The specific equations to be cross-validated were developed by Weltman and coworkers (1987). To the best of this investigator's knowledge, there have been no reports in the literature which have cross-validated these equations for trained male runners. This investigation served to indicate how well the equations predict lactate levels for younger and possibly more highly trained subjects than those in the initial study. If found to be valid, these equations may have significant merit for anyone involved in exercise prescription when equipment for direct measurement is not available.

Purpose of the Study

The purpose of this study was two-fold: 1) to assess the ability of equations developed by Weltman and associates (1987) to predict LT and FBLC (2.0, 2.5, and 4.0 mmol·l⁻¹) from a 3200 m run time for well trained runners; and, 2) to further examine the BLA response to exercise in well trained runners.

Hypothesis

The following null hypothesis was tested at the .05 level of significance: there will be no significant differences between predicted and actual measures of LT and FBLC associated with $\dot{V}O_2$, and velocity.

Assumptions

The following assumptions were made for this study:

1. During each test, the subjects were healthy and performed to the best of their abilities.

2. The practice sessions were sufficient to familiarize the subjects with the equipment and procedures used in the study.

3. The subjects followed instructions regarding pretest restrictions of exercise, dietary intake, rest and other behaviors which may influence test results.

4. Treadmill running results in similar physiological stress as running on a flat surface, such as a track or other hard surfaces.

5. Continuous incremental exercise results in increased BLA concentrations up to a critical level ("threshold") in which exercise can only be maintained for a short period of time leading to exhaustion. The physiological mechanisms involved are complex and not yet completely understood.

7. Blood lactate concentrations are related to endurance running performance.

8. The automated Yellow Springs Lactate Analyzer (Model 23L) used for assay of BLA concentrations provided reliable and accurate measurements.

Delimitations

The delimitations of this study were:

1. The subjects were trained male volunteers both from the University of Wisconsin-La Crosse, and from the community of La Crosse Wisconsin, and were not randomly selected and, therefore, not truly representative of the general population.

2. The subjects were allowed at least 48 hours recovery between tests however no more than 1 week elapsed between tests.

3. Oxygen consumption ($\dot{V}O_2$) and BLA analyses were conducted only

during the VO_2 peak treadmill test and not during the 3200 m run.

Limitations

The limitations of this study were:

1. The determinations of VO_2 peak and BLa were conducted in a controlled laboratory setting, and, therefore, did not truly represent the actual track running conditions of the 3200 m time trial.
2. Changes in physical and/or emotional state, lack of sleep or proper diet, or loss of interest may have influenced the outcome of the tests.
3. At the time of testing, each runner was involved in a training program which included both high and low intensity training sessions.
4. Even though the investigator was skilled in blood sampling procedures and lactate analysis, a degree of error may have occurred which influenced the results.
5. Individual characteristics such as prior training, skill level, inherent motivation, and genetic endowment may have influenced the results of the tests.
6. The 3200 m time trial was run on an indoor 220 yard track as opposed as an outdoor 400 m track used by Weltman and coworkers (1987).
7. Blood samples were acquired by finger prick rather than venous sampling methods.

Definition of Terms

Blood Lactate (BLa) - simply means the appearance and/or presence of lactate in the blood (expressed in millmoles per liter of blood - $\text{mmol} \cdot \text{l}^{-1}$). Lactate concentration increases at a particular exercise intensity, which varies among individuals, and continues to increase as

the work rate increases. During exercise when energy demands are high, the conversion of pyruvate to lactate in the working muscle increases due to an increased rate of glycolysis. As lactate concentration increases, it begins to diffuse into the blood, thus, the appearance of BLA. Many other complex mechanisms interact and contribute to the appearance of BLA.

Fixed Blood Lactate Concentrations (FBLG) - designated as BLA concentrations of $2.0 \text{ mmol} \cdot \text{l}^{-1}$, $2.5 \text{ mmol} \cdot \text{l}^{-1}$, and $4.0 \text{ mmol} \cdot \text{l}^{-1}$. The FBLG were determined by examining the BLA - velocity curve observed during the VO_2 peak test.

$\text{VO}_{2\text{peak}}/\text{LT}$ test - a test utilizing a continuous horizontal treadmill protocol in which speed is progressively increased to exhaustion. From this test values for peak oxygen consumption ($\text{VO}_{2\text{peak}}$), heart rate peak (HR_{peak}), and peak velocity (VEL_{peak}) were obtained. In addition, BLA concentrations were determined by blood analysis following each stage.

The $\text{VO}_{2\text{peak}}$ tests have been found to result in slightly lower VO_2 values compared to $\text{VO}_{2\text{max}}$ tests, which keep the speed constant while increasing the grade of the treadmill (McConnell, 1988; Weltman, Snead, Stein et al., 1990). A horizontal $\text{VO}_{2\text{peak}}$ test more closely simulates actual running and allows velocity to be used a variable for comparison and prediction.

Lactate Threshold (LT) - the intensity during an incremental exercise test at which BLA concentration increases abruptly (in a nonlinear fashion) above a low exercise intensity baseline (Martin & Coe, 1991).

VO₂peak - the peak amount of oxygen taken in, transported, and utilized by the exercising individual during a 1 minute interval of the VO₂peak/LT test.

Trained Subject - any individual who had previous running experience involving intensive endurance training. This included collegiate track and cross-country runners, competitive level triathletes, and road racers (5k, 10k, and marathoners). To be considered trained, an individual must have achieved a value of 60 ml·kg⁻¹·min⁻¹ or higher during the VO₂peak/LT test.

3200 Meter Run Time (RT) - the total time required for a subject to run a 3200 m time trial on an indoor 220 yard track.

Yellow Springs Lactate Analyzer (YSI) - an automated BLA analyzer used in this study to measure lactate concentrations in lysed whole blood samples (extracellular + intracellular).

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

It has been well established that blood lactate (BLa) levels increase in the blood as a result of exercise. Increases in exercise intensity stimulates the rate of glycogenolysis beyond the capacity of aerobic metabolism to oxidize increasing levels of pyruvic acid. The excess pyruvic acid is subsequently converted to lactic acid. The resulting lactic acid is immediately dissociated to lactate ions and hydrogen ions, which then diffuse from the muscle into the blood (Martin & Coe, 1991). It should be noted that almost all tissues of the body produce lactic acid, including red blood cells, but the major source is from exercising muscle (Anderson & Rhodes, 1989; Martin & Coe, 1991; Stainsby & Brooks, 1990).

The level of lactate in the blood is not simply the result of increased production. It has been demonstrated that lactate is utilized to fuel aerobic reactions in exercising muscles, nonexercising muscles, the liver, kidneys, and the heart (Stainsby & Brooks, 1990). Lactate can also be used for glucose formation in the liver, stored as glycogen (via gluconeogenesis) or triglyceride (fat), and used as a fuel for slow twitch (ST) fibers (Brooks, 1985; Gladden, 1989; Stainsby & Brooks, 1990). Therefore, the BLa concentration in the blood reflects a balance between its rate of production, release into the blood, and its removal.

During quiet resting states, even a small amount of lactate is being produced anaerobically by tissues in the body. As exercise intensity increases, lactate concentrations will increase, but may then decrease slightly during some steady state intensities. This indicates that the body is able to clear lactate beyond its rate of production. This ability has been demonstrated in marathoners whose lactate levels have declined towards the end of a marathon (Costill, 1986).

During modest increases in exercise intensity, lactate will continue to increase, but will stabilize (baseline), indicating a balance between its rate of production and uptake (Brooks, 1985; Costill, 1986,). This demonstrates that the body is able to provide enough ATP for energy, primarily through aerobic metabolism. An intensity will eventually be reached when lactate increases abruptly, or in a nonlinear fashion. This represents the intensity level at which lactate production exceeds the body's capability to metabolize, or clear lactate. Lactate will continue to accumulate at a rapid rate above this level. This is partially due to the recruitment of fast twitch (FT) muscle fibers which are more specialized for anaerobic metabolism, thus a higher affinity for lactate production (Costill, 1986; Martin & Coe, 1991; Tesch, Sharp, & Daniels, 1981).

The level at which lactate continues to progressively accumulate designates a transition from primarily aerobic metabolism to greater involvement of anaerobic metabolism (Anderson & Rhodes, 1989). The critical intensity at which a nonlinear and progressive increase in lactate occurs has been identified as the "anaerobic threshold" (Kindermann et al., 1979; Skinner & McLellan, 1980), the "lactate

turnpoint" (Heck et al., 1985), "the onset of BLA accumulation to 4 mM" (Sjodin & Jacobs, 1981), and "lactate threshold" (Anderson & Rhodes, 1989). It is apparent from the literature, that one specific term designating this point has not received universal acceptance. Recently, the use of "lactate threshold" (LT) seems to be favored as an acceptable term.

Influence of Training on Blood Lactate Accumulation

It has been well documented that BLA concentrations at any given absolute and percentage of $\dot{V}O_{2\max}$ are reduced after training (Bouckaert, Vrijens, & Plannier, 1990; Holloszy & Coyle, 1984). These reductions were attributed to lower lactate production and increased uptake by the exercising muscles, partially from an increased respiratory capacity. This has been shown to influence LT determination (Ivy, Whilters, Van Handel, Elger, & Costill, 1980).

Other mechanisms contributing to lower lactate production as a result of training include increased mitochondrial density, a decrease in muscle LDH activity (Holloszy & Coyle, 1984; Sjodin, Jacobs, & Svendenhag, 1982), and greater reliance on fatty acid oxidation following training (Costill et al., 1977).

A product of fatty acid metabolism, citrate synthase (CS), inhibits the glycolytic enzyme phosphofructokinase (PFK) and results in reduced lactate production via glycolysis. Sjodin and associates (1982) have demonstrated an increase in CS activity (+22%) following training in long distance runners, followed by a concomitant decrease in PFK activity. Unlike Ivy et al. (1980), positive relationships were not observed between the onset of BLA accumulation (OBLA) at $4.0 \text{ mmol} \cdot \text{l}^{-1}$ and

the PFK/CS ratio ($r = -.50$) and between OBLA and the LDH/CS ratio ($r = -.08$) in elite runners (Sjodin, Jacobs, & Karlsson, 1981). Non-elite runners displayed modest, but significant correlations ($r = -.79$ and $r = -.66$, respectively). The high velocity at OBLA $4.0 \text{ mmol} \cdot \text{l}^{-1}$ (VEL-OBLA) in relation to the low PFK/CS and LDH/CS ratios in the elite runners was attributed to greater availability of FFA compared to the non-elite runners (Sjodin, et al., 1982). Therefore, along with an increased respiratory capacity in skeletal muscle, it is apparent that the delay of lactate accumulation results from a reduced glycolytic rate, increased pyruvate oxidation, and enhanced fatty acid metabolism at given work rates.

These conclusions were supported by an earlier study (Ivy, Costill, Van Handel, Essig, & Lower, 1981) which demonstrated lower lactate levels when free fatty acids (FFA) were ingested prior to cycle ergometry. A dietary ingestion of glucose significantly raised BLA concentrations above control and FFA trials. Increased FFA content, and a reduced lactate production rate caused a significant shift in LT from 53.9% to 59.8% $\text{VO}_{2\text{max}}$, however, the LT remained the same for both the control and glucose groups (Ivy et al., 1981).

It has been suggested that lower lactate levels observed after training results from decreased rates of appearance, increased rates of clearance, and possibly from enhanced glycogen sparing (Sjodin, Jacobs et al., 1981). MacRae, Dennis, Noakes, and Wiggins (1990) observed increased rates of lactate disappearance during exercise after a 9 week cycling program. No difference was observed in lactate appearance rates between trained (T) and untrained (UT) groups. Muscle glycogen

depletion was lower in the T versus UT group (34% UT versus 16% T), but its contributing role in lactate accumulation was not conclusive due to similar rates of appearance between T and UT groups.

A recent study confirmed that lactate concentrations were lower, appeared more slowly, and cleared more rapidly via oxidation following training (MacRae, Dennis, & Noakes, 1991). In addition, a slower rate of glucose appearance suggested enhanced glycogen sparing. To support this, Sjodin et al. (1982) observed a glycogen sparing effect in elite runners which implied greater reliance on FFA oxidation. MacRae et al. (1991) did not observe gluconeogenesis as a factor in lactate removal. However, in-situ liver perfusions performed in animals revealed enhanced gluconeogenesis following training (Sumida, Urdialis, & Donovan, 1990). This was confirmed by increased lactate uptake and increased glucose output in the livers of the trained animals.

Increased capillary density has been shown to facilitate lactate release from the muscle cells (Komi, Ito, Sjodin, Wallenstein, & Karlsson, 1981; Sjodin & Jacobs, 1981). Correlations between capillary density and performance variables have been significant, ranging from $r = .52$ (Sjodin & Jacobs, 1981) to $r = .80$ (Komi et al., 1981). In contrast, others did not observe a significant relationship between capillary density and performance (Tesch et al., 1981). However, taken together, capillary density and percent ST (%ST) fiber area accounted for 92% of the variance in OBLA $4.0 \text{ mmol} \cdot \text{l}^{-1}$ (Tesch et al., 1981).

Studies confirm that the %ST fibers does influence performance related variables associated with blood lactate parameters. Correlations between %ST and various performance distances have ranged

from $r = .47$ (Farrell et al., 1979) to $r = .83$ (Sjodin et al., 1982). It is apparent from these rather modest correlations, that %ST fibers do not alone determine success in endurance running. Rather, evidence indicates an affinity of ST fibers to become highly trained. To confirm this, Sjodin and coworkers (1982) observed a significant relationship between %ST fibers and the increase in VEL-OBLA following training.

Lactate Threshold Detection

A great deal of controversy exists over both the phenomenon and determination of LT. Consequently, a significant amount of variability exists among laboratories in methods of detection and identification.

LT Defined

The LT has been defined as fixed lactate concentrations of $2.0 \text{ mmol} \cdot \text{l}^{-1}$ (Hagberg, 1984) and OBLA $4.0 \text{ mmol} \cdot \text{l}^{-1}$ (Karlsson & Jacobs, 1982; Kindermann et al., 1979; Sjodin & Jacobs, 1981). Others defined LT as the initial rise in BLA above resting levels (Iwaoka, Hatta, Atomi, & Miyashita, 1988; Tanaka & Matsuura, 1984; Wasserman, Whipp, Koyle, & Beaver, 1973; Yoshida et al., 1987), or a nonlinear rise in BLA with a minimum increase of $1 \text{ mmol} \cdot \text{l}^{-1}$ (Coyle, Coggan, Hemmert, & Walters, 1984; MacDougall, Wenger, & Green, 1991). It has also been defined as the workload preceding an abrupt, or nonlinear increase in BLA above baseline (Ivy et al., 1980; Weltman et al., 1987).

At the initiation of exercise, lactate increases slightly beyond resting levels. Brooks (1985) cautioned that this slight increase should not be interpreted as the LT. In trained runners, lactate will typically increase up to a range of 1.7 to $2.4 \text{ mmol} \cdot \text{l}^{-1}$, then stabilize

up to an intensity which lactate increases abruptly beyond "baseline" (Martin & Coe, 1991). According to these authors, this second "threshold" is most important, as it holds the greatest implications for endurance training and performance.

The traditional methods of LT detection rely on visual inspection of the individual lactate curve. As a consequence of this often highly subjective method, greater potential exists for interinvestigator variability. In efforts to limit the subjective evaluation of LT, more objective methods have employed mathematical models and graphical techniques.

Graphic Detection

Stegmann, Kindermann, and Schnabel (1981) devised a graphical technique based on both exercise and postexercise lactate kinetics. From an identity point on the recovery lactate curve which corresponds to the lactate concentration at the end of exercise, a tangent is constructed to the individual exercise lactate curve. The intercept corresponds to the "Individual Anaerobic Threshold" (IAT). Others who have adopted this technique, have observed greater "precision and flexibility" for identifying LT (Robergs et al., 1990).

Mathematical Model

Robergs and associates (1990) employed a mathematical model previously developed by Beaver, Wasserman, and Whipp (1985). It was based on the characteristic of lactate to increase exponentially during progressive exercise, thus making a linear-based determination difficult. To make a linear-based determination possible, lactate and corresponding workload values, such as VEL and $\dot{V}O_2$, were transformed

into logarithm values. The intercept between the higher and lower regression lines identified the LT. While this model appears highly objective, LT is initially determined by visual inspection. The LT value, determined visually, was included in regression analysis for both groups of data. The two sets of data were then used in the construction of the higher and lower regression lines (Beaver et al., 1985; R. A. Robeigs, personal communication, May, 1991). Beaver and colleagues (1985) supported the validity of this method by demonstrating that the log-log model was a more precise method of LT identification. Conversely, LT determined from a rectilinear plot is less clear, and therefore contributes to greater interinvestigator variability. According to Beaver et al. (1985), the LT by visual inspection was essentially the same as LT determined by the log-log transformation. However, the "resolution" created by the intersection of the log-log regression lines was more precise. Others have observed this distinction (Iwaoka, Fuchi, Higuchi, & Kobayashi, 1988; McLellan & Gass, 1989). The advantage of this method is that it does not depend on individual interpretation.

Exercise Testing Protocols

Horizontal Treadmill

The use of horizontal treadmill tests (HTM) for LT and BLA analysis, especially with competitive runners, has been well documented (Heck et al., 1985; Kumagai et al., 1982; Noakes, Myburgh, & Schall, 1990; Tanaka & Matsuura, 1984; Van Handel, Dengel, Kearney, & Bradley, 1990; Weltman et al., 1987).

In one study, HTM tests elicited slightly lower VO_2 values (< 5%)

at maximal exertion than graded treadmill tests (GTM) used for $\text{VO}_{2\text{max}}$ determination (Weltman, Snead, Stein et al., 1990). Consequently, VO_2 values for HTM tests were given the designation of " $\text{VO}_{2\text{peak}}$ ". The correlations between $\text{VO}_{2\text{max}}$ and $\text{VO}_{2\text{peak}}$ were $r = .94$ ($\text{l}\cdot\text{min}^{-1}$) and $r = .86$ (Weltman, Snead, Stein et al., 1990).

These discrepancies may be explained by differences in muscle fiber recruitment patterns between the two types of incremental tests. In addition, running mechanics and experience may have been limiting factors contributing to lower VO_2 values. Limitations in these two areas would inhibit the ability to maintain speed at near maximum levels, possibly resulting in premature test termination before $\text{VO}_{2\text{max}}$ values were reached. For this reason, HTM tests appear to be more appropriate for competitive runners who have been trained to run at high speeds.

The $\text{VO}_{2\text{peak/LT}}$ protocol has been shown to be a valid and reliable procedure for physiological testing (Weltman, Snead, Stein et al., 1990). Test-retest reliability correlations were high, ranging from $r = .89$ for velocity at LT (VEL-LT) to $r = .96$ for velocity peak (VELpeak). No significant differences were observed for velocity, and the standard error of estimate ranged from ± 6.1 to $\pm 10 \text{ m}\cdot\text{min}^{-1}$. Significant correlations were observed for relative VO_2 -LT ($r = .82$) and $\text{VO}_{2\text{peak}}$ ($r = .71$). The differences were less than $1.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

Stage Duration

Stage duration has received a great deal of attention in the literature (Heck et al., 1985; McLellan, 1985; Weltman, Snead, Stein et

al., 1990). For the purpose of LT and BLA determination, stage length should allow attainment of lactate steady state with concurrent steady state VO_2 and HR values. During submaximal exercise, endurance-trained individuals have been shown to achieve steady states in the above parameters within 3 minutes. In contrast, untrained, or nonendurance trained individuals demonstrated continuous increases during "steady state exercise" (Chwalbinska-Moneta, Robergs, Costill, & Fink, 1989).

For accurate determination of LT, stages lasting a minimum of 3 minutes to 5 minutes have been recommended (Wasserman et al., 1973). Shorter exercise lengths have been shown to overestimate LT, presumably due to the delay in lactate diffusion from muscle to the blood (Heck et al., 1985). This means that higher workloads will be achieved before BLA rises to levels which precludes LT determination. McLellan (1985) observed IAT to be significantly overestimated with 1 minute stages. Heck et al. (1985) observed similar results with 2 minute stages.

Others have observed that lactate concentrations are rarely stable after only 2 minutes (MacDougall et al., 1991). Similarly, it normally takes at least 3 minutes for VO_2 to reach a steady state for workloads below LT (Brooks, 1985; Martin & Coe, 1991). An earlier study (Wasserman, Van Kessel, & Burton, 1967) observed that a true VO_2 steady state was reached within 4 minutes for moderate intensity exercise just below the anaerobic threshold. Arterial lactate responded in the same manner. However, the subjects were not endurance trained which may have explained the delayed steady state.

Stages lasting from 3 to 5 minutes have been commonly used in recent BLA studies (Iwaka, Hatta et al., 1988; Kumagai et al., 1982;

Robergs et al., 1990; Sjodin & Jacobs, 1981; Tanaka & Matsaura, 1984; Tesch et al., 1981; Van Handel et al., 1990; Weltman et al., 1987; Weltman, Seip et al., 1990).

Heck et al. (1985) observed slow but notable increases in lactate beyond 5 minutes in highly trained runners. Three minute stages were shown to overestimate the workload at the maximal lactate steady state. This implied that 3 minute stages may delay diffusion of lactate from the muscle to the blood. Nevertheless, Heck and associates (1985) observed that loading durations between 3 and 5 minutes had minimal effect on LT detection ($r = .971$). This would be expected because the amount of lactate produced at threshold intensity was quite small. Consequently, changes in respect to time were minimal.

Hagberg (1984) suggested that a series of 10 minute treadmill runs performed on successive days provided a more accurate assessment of VO_2 and BLA kinetics in response to exercise. Contrary to this evaluation, a continuous 3 minute stage test provided similar values of VO_2 and VEL at LT and FBLC when compared to a series of 10 minute discontinuous runs (Weltman, Snead, Stein et al., 1990). Validity correlations ranged from $r = .75$ (VO_2 -LT) to $r = .90$ (VO_2 -2.5 and VO_2 -4.0). Velocity correlation coefficients ranged from $r = .87$ to $r = .97$. Apparently, a continuous VO_{2peak} /LT treadmill protocol with 3 minute stages provided valid and reliable determinations of VO_2 and VEL at LT and FBLC of 2.0, 2.5, and 4.0 $mmol \cdot l^{-1}$. Hagberg (1984) suggested that a series of 10 minute exercise bouts provided more valid data because they elicit physiological stress similar to competition and training. However, a continuous VO_{2peak} /LT protocol, which requires only one visit to the

laboratory, also provided satisfactory results.

Stage Loading

To accurately detect LT, most investigators agreed that stage increments must be relatively small. Modest increments reduce the transient increases in VO_2 and lactate such as occurs at the onset of exercise and with significant increases in workload (Kindermann et al., 1979; Wasserman et al., 1967). Karlsson and Jacobs (1982) found increments of 50 Watts (W) or 2 km per hour ($\text{km}\cdot\text{h}^{-1}$) to be valid and reliable for lactate testing. Heck et al. (1985) argued that 50 W increments per stage were too large and caused steep increases in lactate which prevented attainment of steady state values. However, these authors made this observation using only 2 and 3 minute stage durations. In contrast, Kindermann et al. (1979) used 2 $\text{km}\cdot\text{h}^{-1}$ ($33\text{ m}\cdot\text{min}^{-1}$) increments in running velocity with 3 minute stages. Lactates stabilized from the initial speed of 8 through 12 $\text{km}\cdot\text{h}^{-1}$, at which point lactate began to increase nonlinearly. Oxygen consumption and HR increased in a linear fashion as VEL increased. These authors observed that in order for HR, VO_2 , and lactates to remain stable for 30 minutes at $4.0\text{ mmol}\cdot\text{l}^{-1}$, treadmill speed had to be gradually decreased (Kindermann et al., 1979). This demonstrated that lactate, VO_2 , and HR kinetics were time and workload dependent variables. This conclusion was later confirmed by Heck and associates (1985), who found similar results when workload duration and increments were altered. During a 30 minute test, BLa stabilized while HR continued to increase (Heck et al., 1985). Kindermann et al. (1979) concluded that the increase in HR was caused by an increase in core temperature and not anaerobic metabolism.

Therefore, HR may not always signal the onset of anaerobiosis.

Recent studies using trained runners have adopted substantially lower workload increments. Weltman et al. (1987) used increments of 10 $\text{m}\cdot\text{min}^{-1}$ ($0.6 \text{ km}\cdot\text{h}^{-1}$; 0.37 miles per hour [mph^{-1}]) for LT and FBLC detection. Investigators from the United States Olympic Committee employed 15 $\text{m}\cdot\text{min}^{-1}$ ($0.90 \text{ km}\cdot\text{h}^{-1}$; 0.56 mph^{-1}) increments (P. J. Van Handel, personal communication, November, 1990). Heck and associates (1985) varied the workload increments between 6.0 $\text{m}\cdot\text{min}^{-1}$ ($0.35 \text{ km}\cdot\text{h}^{-1}$; 0.22 mph^{-1}) and 12.0 $\text{m}\cdot\text{min}^{-1}$ ($0.72 \text{ km}\cdot\text{h}^{-1}$; 0.45 mph^{-1}) depending on lactate levels from previous tests. Therefore, testing was more individualized. The purpose of employing small load increments is to increase test sensitivity for accurate measurement of lactate concentrations, and to isolate LT. However, small increments can make visual detection quite difficult, as the transient increases in lactate are less obvious. This can result in considerable variance in LT detection between individual observers (Heck et al., 1985).

Other investigators testing trained runners have commonly used larger workload increments ranging from 20 $\text{m}\cdot\text{min}^{-1}$ [$1.2 \text{ km}\cdot\text{h}^{-1}$; 0.74 mph^{-1}] (Iwaoka, Hatta et al., 1988; Kumagai et al., 1982; Tanaka, Matsuura et al., 1984), to 33 $\text{m}\cdot\text{min}^{-1}$ [$2 \text{ km}\cdot\text{h}^{-1}$; 1.2 mph^{-1}] (Lehmann, Berg, Kapp, Wessinghage, & Keul, 1983; Sjodin & Jacobs, 1981). The majority of these studies also used longer stage durations, ranging from 3.5 to 6 minutes. The extended durations allowed a sufficient amount of time for reaching steady states, thus compensating for the larger loading patterns. Several studies (Weltman et al., 1987; Weltman, Seip et al., 1990; Weltman, Snead, Stein et al., 1990) consistently employed

3 minute stages with $10 \text{ m} \cdot \text{min}^{-1}$ speed increases.

There is an obvious need for standardized methods. However, the existing evidence does indicate that stage duration and loading patterns need to be small enough and long enough to ensure accurate LT and FBLC determination.

Initial Workload

To avoid running inefficiency which may affect VO_2 and lactate kinetics, initial workload should be set at or above 30% $\text{VO}_{2\text{max}}$ (MacDougall et al., 1991). However, LT in trained runners often occurs above 60% $\text{VO}_{2\text{max}}$, generally ranging from 75% to 90% $\text{VO}_{2\text{max}}$ (Martin, Vroon, May, & Pilbeam, 1986; Weltman et al., 1987). Accordingly, initial loads approximating 50% to 60% $\text{VO}_{2\text{max}}$ may be appropriate for trained runners.

In support of this, Martin and Coe (1991) suggested that VEL-LT in trained runners may occur from 75% to 90% $\text{VO}_{2\text{peak}}$ velocity ($\text{VO}_{2\text{peak}}\text{-VEL}$) depending on fitness level. When equating VEL and VO_2 with intensity, the percent of VELpeak is slightly lower (-4% to -5%) than the corresponding percent $\text{VO}_{2\text{peak}}$ ($\%\text{VO}_{2\text{peak}}$).

Weltman and associates (1987) used an initial load of $150 \text{ m} \cdot \text{min}^{-1}$ ($9.0 \text{ km} \cdot \text{h}^{-1}$; 5.59 mph^{-1}), which corresponded to a mean of 52.4% of $\text{VO}_{2\text{peak}}\text{-VEL}$ in trained runners. This was a conservative setting, as most trained runners would most likely experience significant reductions in running efficiency at this speed. In practical terms, $150 \text{ m} \cdot \text{min}^{-1}$ equates with a 10:44 minute pace per mile. This pace is normally far below even a long, slow, aerobic pace for trained runners. Van Handel (personal communication, November, 1990) indicated that runners tested

at the United States Olympic Training Center (Colorado Springs, CO) are typically started at 7:00 minute pace per mile ($230 \text{ m} \cdot \text{min}^{-1}$).

Heck and coworkers (1985) set initial speeds according to the fitness level of each individual. Velocities ranged from $156 \text{ m} \cdot \text{min}^{-1}$ to $203 \text{ m} \cdot \text{min}^{-1}$. This seemed appropriate since their subject pool varied from "healthy" to "elite". Noakes et al. (1990) tested experienced marathoners and ultra-marathoners, starting them at $166.7 \text{ m} \cdot \text{min}^{-1}$. Other studies were within this range, with initial settings of $161 \text{ m} \cdot \text{min}^{-1}$ (Kohrt et al., 1989), $180 \text{ m} \cdot \text{min}^{-1}$ (Kumagai et al., 1982; Tanaka, Matsuura et al., 1984), and $204 \text{ m} \cdot \text{min}^{-1}$ (Fohrenbach et al., 1987).

The initial load ultimately determines the success or failure of an incremental BLA test. If set too high, lactate levels may increase sharply upon initiation of exercise, and possibly remain elevated throughout the test. Thus, LT would go undetected, and corresponding workloads would be overestimated (Heck et al., 1985). Initial work loads set too low impede running efficiency and may cause erroneous VO_2 and lactate values. Excessively low initial settings are likely to increase test time, which in turn may cause increased HR, VO_2 , and lactate values. In addition, performance may also be impaired during the latter stages of an extended test due to leg fatigue, fluid loss, and lack of motivation. In prolonged tests in which there is excessive fluid loss, higher lactate concentration values result from the impending hemoconcentration (Martin & Coe, 1991).

Transfer of Test Conditions

The ability to predict BLA parameters from a field test is dependent upon how well laboratory testing conditions transfer to field

settings. The same is true if test results are used to predict performance, or if applied to training programs. Therefore, it is imperative that laboratory conditions simulate actual training, or running conditions as closely as possible.

Heck and coworkers (1985) compared lactate values between running on various outdoor surfaces and running on a treadmill set at different grades of inclination. The values obtained from running on an artificial surfaced track most closely corresponded to treadmill value at a 1% grade. The 1% grade accounted for wind resistance, which is not present in a laboratory setting. It also accounted for the reduced energy cost of running on a moving surface as compared to a fixed surface.

The existing evidence strongly supports the use of HTM testing with runners. However, only one other study reviewed utilized a 1% treadmill grade (Fohrenbach et al., 1987), while the majority, including Weltman and associates (1987), kept treadmill grade at 0%.

The advantages and benefits of laboratory testing with HTM tests are quite apparent. It has been demonstrated that training pace, which is the preferred training index for competitive runners, can be easily transferred to field settings (Fohrenbach et al., 1987; Heck et al., 1985). In addition, corresponding HR, lactate, and VO_2 values can be used to fine-tune training sessions (Heck et al., 1985). A laboratory environment is controlled, and is, therefore, an ideal setting for the assessment of training programs and fitness levels.

Effect of Rest Period

Most studies in the literature obtained blood samples immediately

at the end of each stage, or within 30 seconds (Di Vico, 1989; Weltman et al., 1987; Weltman, Seip et al., 1990). Others sampled blood immediately at the end of each stage, followed by a 1 to 2 minute rest (Robergs et al., 1990). Heck and associates (1985) demonstrated that the rest period and its effect on lactate values was not statistically significant. However, small shifts toward higher speeds at LT were observed ($4.2 \text{ m} \cdot \text{min}^{-1}$) for each 0.5 minute of rest (Heck et al., 1985). This was attributed to lactate clearance during the rest period. Therefore, the pause should be kept as brief as possible.

Blood Sampling by Finger-Tip Puncture

Finger-Tip versus Vena Puncture

In recent years, invasive measurement of BLA has been simplified by the advent of simple microanalysis techniques. Newer methods require only a small lancet puncture of an earlobe or a fingertip. In contrast to venous or arterial punctures, multiple samples can be obtained from one or several subjects using the finger "stick" technique. This method is particularly useful when time is limited. Another advantage is that finger punctures cause less trauma to the subject than vena-puncture or indwelling catheter techniques (Van Handel et al., 1990). In addition, fingertip punctures provide sufficient amounts of blood for duplicate analysis. The availability of semiautomated lactate analyzers also makes immediate and uncomplicated assay possible (Van Handel et al., 1990). These advantages, along with the latest technological advances, have led others to adopt fingertip blood collection techniques to quantitate BLA in response to exercise (Fohrenbach et al., 1987; Weltman, Seip et al., 1990; Weltman, Snead, Stein et al., 1990; Weltman,

Snead, Stein et al., 1990; Weltman et al., 1987).

In contrast, spectrophotometric or fluorometric techniques involve complicated and time consuming laboratory procedures. The enzymatic methods, while considered the reference methods, do not allow immediate viewing of results. Rather, the samples must be deproteinized, centrifuged, and incubated up to 45 minutes before assay.

Precautions and Limitations

The simplicity of the fingertip sampling technique makes it ideal for monitoring training and/or conducting pre and postseason fitness assessments. However, limitations inherent to sampling blood by fingertip puncture can lead to difficulties in analysis. For most runners, the interruption after each stage is undesirable, especially when approaching peak velocities (Martin & Coe, 1991). Another liability of analyzing blood from a fingertip puncture is the potential of contamination from interstitial fluid and sweat (Di Vico, 1989; Martin & Coe, 1991; Van Handel et al., 1990).

Van Handel and associates (1990) confirmed that even a small amount of sweat contained large concentrations of lactate. Blood lactate values above $50 \text{ mmol} \cdot \text{l}^{-1}$ were observed from a 25 microliter sample of sweat. To prevent contamination, the sampling site was completely dried with a gauze pad. To prevent contamination from interstitial fluid, the first drop of blood was wiped away before sample collection (Martin & Coe, 1991; Van Handel et al., 1990). In addition, Stainsby and Brooks (1990) noted that glycolysis in the epidermal cells of the skin caused release of lactate during rest and exercise.

Blood composition can similarly be altered by massaging the

puncture site in an effort to enhance blood flow, and therefore, must be avoided. Di Vico (1989) found "inconsistent results" by massaging the finger during sampling. To alleviate potential blood flow problems, Di Vico (1989) prewarmed the hand at 43-49 degrees celsius. Van Handel suggested that warming the hand was unnecessary, as long as the lancet puncture was firm (personal communication, November, 1990).

Martin and Coe (1991) suggested that a firm puncture ensures that blood is "essentialized arterialized", rather than predominantly capillary blood, which is the result of the arterioles being severed. Di Vico (1989) suggested that arterialized capillary BLA samples are more representative of arterial BLA when compared to samples of venous blood, because blood taken from the tissue is not "metabolically active."

It is apparent that using fingertip punctures in conjunction with semiautomated lactate analyzers has several distinct advantages, as well as several methodological difficulties. However, the methods have been widely accepted and validated (Bishop, Smith, Murphy, & Kime, 1990; Di Vico, 1989; Forrest, Morton, & Lambardarios, 1990; Sjodin & Jacobs, 1981; Van Handel et al., 1990).

Blood Sample Treatment: NaF-TX100

Assay of Untreated Whole Blood

The use of the YSI Model 23L semiautomated lactate analyzer with untreated whole blood requires immediate assay. Following blood sample collection, expedient assay must be carried out to prevent clotting, and to prevent lactate values from increasing. Di Vico (1989) observed that time delay increased the lactate values due to lactate production in the

glycolytic erythrocytes. In addition, lactate concentrations with whole blood resulted in lower values than those observed by using enzymatic methods since only extracellular lactate was measured (Van Handel et al., 1990). In resting conditions, small differences (10%) existed between whole blood analyzed immediately by an automated lactate analyzer and enzymatic assay (Forrest et al., 1990). However, the differences increased beyond 30% during exercise (Forrest et al., 1990). Van Handel et al. (1990) observed similar patterns.

Storage and Assay

In addition to these limitations, immediate analysis of whole blood precludes storage for later and/or duplicate analysis. Therefore, methods which utilize semiautomated assay of whole blood may not be practical for field or laboratory testing where multiple samples require preservation for later analysis.

Recently, simplified techniques have been developed for collection, storage and analysis of whole blood samples which compare favorably with standard enzymatic methods (Van Handel et al., 1990). No significant differences in lactate values were found between fingertip samples treated with NaF-TX100 solution assayed automatically (YSI Model 23L), and venous blood samples assayed using enzymatic methods. The mean differences were less than $0.3 \text{ mmol} \cdot \text{l}^{-1}$, with a correlation of $r > .99$ ($\text{SEE} = 0.27$).

Venous blood diluted in NaF-TX100 and assayed automatically (YSI 23L) was found to be in close agreement ($r = .996$) with venous blood analyzed with a standard enzymatic method [Boehringer-Mannheim] (Foxdal, Sjödin, Rudstam, Ostman, & Hedenstierna, 1990). No significant

differences between methods were observed (Foxdal et al., 1990). During cycle ergometry, fingertip capillary whole blood was found to be 8% higher than venous whole blood when both were prepared with NaF-TX100 and analyzed with a YSI 23L [$r = .996$] (Foxdal et al., 1990). This was attributed to lactate uptake and utilization by muscles in the inactive forearm, and other organs such as the heart and liver (Stainsby & Brooks, 1990). Therefore, these differences may not appear during treadmill exercise when both arms remain active.

Lactate values of fingertip samples prepared in NaF-TX100 and stored in a capped container remained stable for up to 72 hour at room temperature. Duplicate samples assayed immediately and after 16 hours displayed a difference of only $.094 \text{ mmol} \cdot \text{l}^{-1}$ with a standard error of estimate of $0.157 \text{ mmol} \cdot \text{l}^{-1}$. Samples preserved in the same manner remained stable for up to 10 days when refrigerated at 4.0 degrees celsius, with some individual variability (Van Handel et al., 1990).

In addition to the aforementioned benefits, calibration and use of the YSI 23L lactate analyzer is simplified by the 1:3 dilutions of whole blood with the NaF-TX100 solution (25 μl blood to 5 μl NaF-TX100). As a result, the machine typically read values from 1.0 to possibly 7.0 $\text{mmol} \cdot \text{l}^{-1}$. Corrected values ($\times 3$) equalled 3.0 to 21 $\text{mmol} \cdot \text{l}^{-1}$. This was a distinct advantage because the analyzer is unable to register values above $15 \text{ mmol} \cdot \text{l}^{-1}$ from undiluted samples. Linearity also diminished as values approached $15 \text{ mmol} \cdot \text{l}^{-1}$ (Van Handel et al., 1990). Therefore, the present methods significantly increased accuracy and simplicity. In addition, because diluted values rarely surpassed $7.0 \text{ mmol} \cdot \text{l}^{-1}$, only calibration to the $5 \text{ mmol} \cdot \text{l}^{-1}$ standard was required (Van Handel et al.,

1990).

The evidence supports the use of fingertip whole blood diluted and preserved in a cell lysing reagent (NaF-TX100) as a valid and reliable method of lactate analysis. The use of this treatment method, along with the YSI 23L lactate analyzer, may provide simplified and practical techniques for use in both field assessments and laboratory research.

Validation of YSI (Model 23L) Lactate Analyzer

The YSI 23L been utilized in many physiological studies (Duggan, & Tebbutt, 1990; Iwaoka, Fuchi et al., 1988; Kohrt et al., 1989; O'Toole, Douglas, & Hiller, 1989; Pierce, Weltman, Seip, & Snead, 1990; Weltman et al., 1987, Weltman et al., 1989). Recently, validation studies of the YSI Model 23L lactate analyzer have been conducted.

The manufacturer of the 23L (Yellow Springs Instrument Company) demonstrated a high correlation ($r = .997$) between the YSI 23L and a photoenzymatic LDH-NAD reference method. This correlation was observed using unlysed whole blood. Correlations between the 23L and the reference method using total blood was higher ($r = .999$). Direct comparison was possible since both methods for assay of total blood involved lactate release from the red blood cells. Another report observed high correlations ($r = .994$) between the 23L and a continuous-flow enzymatic method (Weil, Leavey, Rackow, Halfman, & Bruno, 1986). Similar comparisons between the YSI 23L and fluorometric enzymatic methods revealed close agreement in lactate measurements, with correlations of $r = .997$ (Foxdal et al., 1990), and $r = .9995$ (Di Vico, 1989). Foxdal et al. (1990) utilized the Boehringer-Mannheim reference method, and prepared the blood samples with a NaF-TX100

solution.

A more recent study examined the intermachine reliability of four YSI 23L lactate analyzers (Bishop et al., 1990). They found correlations of $r \geq .96$ between duplicate samples, and between the four machines. Similar to Van Handel et al. (1990), the red cell lysing reagent TX-100 was prepared with the YSI buffer solution. To test the influence of storage, measurements were taken after 1, 2, 4, and 7 days. A storage reagent was used, but not named in the study. In contrast to Van Handel et al. (1990), lactate values were less stable when blood samples were stored in TX-100, particularly at moderate and high exercise levels. As expected, lactate concentrations were consistently higher in samples treated with TX-100.

Prediction of LT and FBLC From Running Performance

The conceptual framework for the present thesis research was based on the first of a series of investigations carried out by Weltman and associates (1987). Their purpose was to determine the effectiveness of 3200 m run time to predict LT and FBLC of 2.0, 2.5, and 4.0 mmol·l⁻¹. A secondary purpose was to develop a means to obtain the desired information by simple and inexpensive noninvasive procedures. Finally, the intent was to provide evidence in support of using LT and FBLC for exercise prescription, and as predictors of running performance. If valid, a simple field test such as a 3200 m run could be a valuable training tool for coaches and endurance athletes.

Weltman and colleagues (1987) developed a series of equations to predict $\dot{V}O_2$ and running VEL at LT and FBLC of 2.0, 2.5, 4.0 mmol·l⁻¹ and peak values. Forty-two male runners (mean age = 31.1 ± 8.3 years)

participated in the study. All were "experienced" runners who competed regularly, and demonstrated a mean $\text{VO}_{2\text{peak}}$ value of 64.8 ± 6.5 . This indicated a high level of fitness, but not at levels of "elite" runners. The results indicated that a 3200 m performance time was an accurate and valid predictor of VO_2 and VEL at LT and FBLC of 2.0, 2.5, 4.0 $\text{mmol}\cdot\text{l}^{-1}$, and peak values. Equations to predict VO_2 at LT, FBLC of 2.0, 2.5, 4.0, and $\text{VO}_{2\text{peak}}$ produced correlation coefficients of $r = .77$, $r = .75$, $r = .79$, $r = .79$, and $r = .77$, respectively. Correlations for the VEL equations were significantly higher, ranging from $r = .85$ to $r = .88$. There were no significant differences in the means of predicted versus actual values for any variable. Data from the cross-validation group demonstrated similar results. This study provided evidence for the use of a 3200 m run time as a valid predictor of VO_2 and VEL corresponding to LT and FBLC for trained male runners (mean age $= 31.1 \pm 8.3$ yr).

Using the same testing design, similar findings were recently reported for a heterogeneous group of women (Weltman, Seip et al., 1990), and for a group of untrained males (Weltman et al., 1989). These finding indicated that the state of training does not affect the ability of a 3200 m run time to predict LT and FBLC.

Tanaka et al. (1985) demonstrated that a 1500 m performance time accurately predicted anaerobic threshold ($\text{VO}_{2\text{-AT}}$) in highly trained male runners (mean $= 19.4 \pm 2.2$ yr; $n = 53$). Testing procedures were very similar to Weltman et al. (1987). The correlation produced was $r = .831$ and the standard error of estimate was $2.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. The following four variables were included in this prediction equation:

VO_2max , 1500 m run, total running distance (on treadmill), and chronological age. When variables were isolated to VO_2max and 1500 m run time, the correlation was reduced to $r = .806$, and standard error of estimate increased to $2.76 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. This value compared to $r = .73$ for $\text{VO}_{2\text{peak}}$ found by Weltman et al. (1987) based on 3200 m run time.

Cross validation using 21 different, but "matched", runners (Tanaka et al., 1985) produced a correlation coefficient of $r = .927$ for $\text{VO}_2\text{-AT}$. Similar cross-validation by Weltman et al. (1987) resulted in a correlation coefficient of only $r = .70$ for $\text{VO}_2\text{-LT}$. Both studies defined LT and AT as a systematic initial increase in lactate above resting baseline.

The existing evidence indicated that field tests such as a 3200 or 1500 m run can accurately predict BLA parameters. This has been attributed to the significant relationship that exists between BLA parameters and performance.

Performance Related Variables

VO_2max

Several physiological variables have been found to be highly correlated to running performance. The variable that has received the most attention is VO_2max , which is considered to be the best indicator of cardiorespiratory fitness levels (American College of Sports Medicine, 1990). Others have suggested that it is the best physiological predictor of endurance performance (Costill, 1967; Costill et al., 1973; Foster et al., 1978). However, VO_2max only indicates the performance capacity for maximal efforts of relatively short duration (one to three minutes), which ultimately lead to exhaustion.

McConnell (1988) revealed a wide range of correlation coefficients between performance and $\dot{V}O_{2\max}$ ($r = .08$ to $.91$) which were attributed to a wide variance in fitness levels of the subjects. Consistently lower correlations were observed by Kumagai et al. (1982) for distances of 5k, 10k, and 10 miles ($r = -.65$, $r = -.67$, and $r = -.57$, respectively). Using highly trained runners, Conley and Krahenbuhl (1980) reported a correlation of $r = -.12$ between $\dot{V}O_{2\max}$ and performance. Other investigators had similar findings; $r = .55$ to $.81$ (Noakes et al., 1990), $r = .44$ to $.69$ (Iwaoka, Hatta et al., 1988); $r = .59$ to $r = .80$ (Iwaoka, Fuchi et al., 1988); and $r = .63$ (Lehmann et al., 1983). Based on these findings, it would seem that $\dot{V}O_{2\max}$ is a rather weak predictor of endurance performance, and, therefore, may not account for all of the variance in endurance events.

The $\dot{V}O_{2\max}$ was also found to be a good predictor of performance in all three events for a one-half iron-man distance triathlon. Correlations for running, cycling, and swimming were $r = -.73$, $r = -.83$, and $r = -.87$ respectively (Kohrt et al., 1989). Intersubject variability was great as evidenced by $\dot{V}O_{2\max}$ values (50.9 to $67.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), and triathlon times ($4:41.20$ to $6:45.10$), which may have accounted for the strong relationship.

Running Economy

Running economy has been shown to be related to success in endurance running events. It is simply a measure of the oxygen consumption ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) associated with a given submaximal treadmill velocity (Daniels, 1985). However, the correlations between running economy and distance running performance are relatively low, with values

typically ranging from $r = .10$ to $.61$ (Noakes et al., 1989) and $r = .47$ to $.53$ (Farrell et al., 1979). A stronger relationship was observed in a group of highly trained runners ($r = .83$), similar in both VO_{2max} and running ability (Conley & Krahenbuhl, 1980). Subjects in Farrell et al. (1979) and Noakes et al. (1989) varied to a much greater degree.

Muscle Fiber Type

Studies which examined the relationship between performance and the %ST fibers, observed only modest correlations, ranging from $r = -.33$ to $-.54$ (Foster et al., 1978), $r = .47$ to $.53$ (Farrell et al., 1979), and $r = .55$ to $.69$ (Sjodin & Jacobs, 1981). Others demonstrated significantly higher correlations ($r = .80$) between %ST and the average pace for a marathon (Komi et al., 1981). Significant but rather low correlations were observed between capillary density and performance ranging from $r = .52$ to $.63$ (Sjodin & Jacobs, 1981), to $r = .80$ (Komi et al., 1981).

Fractional Oxygen Use

The fractional use of oxygen ($\%VO_{2max}$) used at submaximal intensities had shown to be significantly related to endurance performance (Costill, 1972). Noakes and coworkers (1989) found percent of VO_{2max} to be a reasonable predictor of performance, demonstrating correlations from $r = .76$ to $.90$.

LT and FBLO

Recent studies have demonstrated that certain BLA parameters are more highly related to endurance performance than VO_{2max} , running economy, %ST fibers, and $\%VO_{2max}$.

Farrell and associates (1979) demonstrated that treadmill VEL corresponding to the onset of plasma lactate accumulation (OPLA) had the strongest relationship to performance ($r = .91$ to $.98$). Performances ranged in distance from 3.2 km to 42.2 km. This relationship existed for the fastest and slowest runners, which indicated that the "relationship is independent of the competitive level of the runner" (Farrell et al., 1979, page 340). Noakes and colleagues (1989) confirmed these findings, with correlations between performance and treadmill VEL at the "lactate turnpoint" that ranged from $r = .91$ to $r = .93$. These were observed in runners who competed in races of 10 km to 42.2 km. In addition, for both marathoners and ultra-marathoners, correlations were still quite high for the same distances [$r = .91$] (Noakes et al., 1989).

Lactate threshold has consistently produced higher correlations with performance as compared to a fixed lactate concentration of $4.0 \text{ mmol} \cdot \text{l}^{-1}$ (OBLA $4.0 \text{ mmol} \cdot \text{l}^{-1}$). LT was found to be highly related ($r = .82$) to 1500 m performance (Tanaka et al., 1983). In contrast, OBLA $4.0 \text{ mmol} \cdot \text{l}^{-1}$ and 1500 m run time was only modestly related ($r = .68$). Researchers have attempted to justify the $4.0 \text{ mmol} \cdot \text{l}^{-1}$ lactate concentration as superior training threshold to LT (Heck et al., 1985; Kindermann et al., 1979). Others have demonstrated its limitation as a "protocol-specific" measurement (Stegmann & Kindermann, 1982).

Yoshida and associates (1987) further demonstrated that OBLA $4.0 \text{ mmol} \cdot \text{l}^{-1}$ was only moderately related to performance ($r = .70$). Similar results were observed between 5 km performance and OBLA $4.0 \text{ mmol} \cdot \text{l}^{-1}$ (Iwaoka, Fuchi et al., 1988). Kumagai and associates (1982) observed

significantly higher correlations between LT and performances of 5 km ($r = -.95$), 10 km ($r = -.89$), and 10 miles ($r = -.835$). In contrast, others observed unusually low correlations between LT and performances of 5 km to 1500 m ranging from $r = -.178$ to $-.71$ (Iwaoka, Hatta et al., 1988). These findings were attributed to the relative homogeneity of performance times.

The significant relationship between BLA parameters in both short, and long distances has been well documented. In particular, marathon performance has been found to be highly related to LT, ranging from $r = .92$ (Noakes et al., 1990), $r = .96$ (Sjodin & Jacobs, 1981), to $r = .98$ (Farrell et al., 1979). The high correlations reported between LT and marathon performance can be expected trained runners typically run the marathon at a pace just below LT (Noakes et al., 1990; Rhodes & McKenzie, 1984; Sjodin & Jacobs, 1981).

The strong relationship between BLA parameters and performance have prompted others to suggest that LT and FBLO can be used as indexes of submaximal fitness (Hagberg, 1984; Weltman et al., 1978; Yoshida et al., 1987;). Yoshida et al. (1987) suggested that LT is the single best index for aerobic capacity and endurance running performance. This conclusion is based on the findings that LT is highly related to both $\dot{V}O_{2\max}$ and endurance performance (Farrell et al., 1979). Similar to LT, FBLO have been found to be highly related to performance and submaximal fitness levels. Fohrenbach and colleagues (1987) observed close relationships between velocities at 2.5, 3.0, 4.0 $\text{mmol}\cdot\text{l}^{-1}$ and marathon pace ($r = .88$ to $.99$). However, the highest collective correlations were found at 2.5 and 3.0 $\text{mmol}\cdot\text{l}^{-1}$ ($r = .88$ to $.99$). It was suggested

that a pace which elicits lactate concentrations of 2.0 to 3.0 mmol·l⁻¹ is a reasonable level which highly trained runners can maintain throughout a marathon. In addition, they proposed that a pace at maximal lactate steady state is achieved at approximately 3.0 mmol·l⁻¹. This study provided strong evidence for the use of FBLC in training and for establishing performance goals.

Critical Training Intensities

The evidence is clear that strong relationships between lactate variables and performance exist over a wide range of competitive levels, VO₂max values, and race distances. The following discussion provides additional support for the validity of LT and FBLC as critical training intensities for endurance conditioning and performance.

Percent of Maximum Concept

It has been accepted that training intensity is one of the key variables which influences a training effect. The American College of Sports Medicine (1990) recommended that intensity of training be carried out at 60% to 90% of maximum heart rate (HR_{max}), or 50% to 85% of VO₂max or heart rate reserve max (HRR_{max}). Recently, the validity for the use of the percent-of-maximum concept has been challenged (Katch et al., 1978; Sady, Katch, Freedson, & Weltman, 1980; Weltman, Snead, Seip et al., 1990; Weltman et al., 1989). These investigators suggested that training intensity based on percent of VO₂max, HR_{max}, and HRR does not provide the optimal physiological stress for trained individuals as when LT and FBLC are applied. Therefore, it was proposed that use of the current ACSM guidelines (1990) may be more appropriate for the general public than for endurance trained athletes focussing on optimal

performance.

LT and FBLC

In trained runners, LT and FBLC (2.0, 2.5, & 4.0 mmol·l⁻¹) were achieved at significantly greater percentages of VO₂max, HRRmax, and HRmax than recommended for the general population (Weltman, Snead, Seip et al., 1990). It was, therefore, recommended, that when LT is the criterion intensity, trained runners should train at 90% HRmax, 95% HRRmax, or 90% VO₂max. Likewise, the 2.0 mmol·l⁻¹ optimal intensities corresponded to 95% HRmax, 90% HRRmax, or 95% VO₂max. For 2.5 mmol·l⁻¹, 95% HRmax, HRRmax, or VO₂max was the recommended intensity. It was suggested that training at $\geq$ 95% HRmax, HRRmax, or VO₂max ensure the proper intensity if the 4.0 mmol·l⁻¹ index was used. These findings were expected because the guidelines established for the general public would not be expected to have specific application for trained individuals. For example, it is well known that trained runners can maintain a significantly higher percentage of their VO₂max and training HR for longer periods of time than less trained individuals (Costill, 1986).

Training intensities based on lactate parameters often utilize indices of VO₂, HR, and perceived exertion as training guides. These methods of assigning training intensities are quite effective and easy to use in monitoring exercise. However, VEL-LT and VEL-FBLC have been suggested as more effective methods of monitoring training intensities, especially for competitive endurance athletes (Farrell et al., 1979; Fohrenbach et al., 1987; Noakes et al., 1990). In support of this, VEL has been shown to be better predictor of endurance performance than are VO₂ and HR (Noakes et al., 1990). For runners who competed in races

between 10 km and 42.2 km, VEL-LT was highly correlated to performance [$r = -.90$ to $-.98$] (Farrell et al., 1979; Komi et al., 1981; Noakes et al., 1990; Yoshida et al., 1987). Lower, but significant correlations were observed between VO_2 ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) at LT and performance [$r = -.64$ to $-.94$] (Farrell et al., 1979; Kumagai et al., 1982). Fohrenbach and colleagues (1987) observed correlations ranging from $r = .88$ to $r = 0.99$ between marathon pace and treadmill velocities at $2.5 \text{ mmol} \cdot \text{l}^{-1}$ and $3.0 \text{ mmol} \cdot \text{l}^{-1}$. Exercise prescription according to BLA parameters may also apply to older endurance athletes (Duggan & Tebutt, 1990), or to individuals with heart disease (Coyle et al., 1983). These researchers suggested that adaptations in peripheral mechanisms compensate for limitations in central hemodynamics caused by age or heart disease, and that BLA parameters are closely related to these adaptations.

Training Effects

The existing evidence demonstrated that training at or above LT and FBLC can lead to significant improvements in performance. It has been suggested that these improvements are the result of increased VEL-LT and FBLC (Acevedo & Goldfarb, 1989; Davis et al., 1979; Denis et al., 1982; Henritze et al., 1985; Pierce, et al., 1990; Sady et al., 1980). Therefore, it appears that variables related to LT and FBLC can be "trained".

In support of this concept, LT in trained runners typically occurs at intensities ranging from 70% $\text{VO}_{2\text{max}}$ (Farrell et al., 1979) to 86% (Iwaka, Fuchi et al., 1988; MacDougall, 1977). For elite male runners (400 m to 42.2 km specialists) LT has been shown to occur from 83% to 88% $\text{VO}_{2\text{max}}$ (Svendsen & Sjodin, 1984). In contrast, LT in untrained

subjects typically occurs at 40% (Davis et al., 1979) to 65% (Weltman et al., 1989). This evidence suggests that LT and FBLC may be improved through training.

The magnitude of change is obviously dependent upon initial fitness levels. Davis and coworkers (1979) demonstrated that sedentary subjects were able to increase their absolute $\text{VO}_2\text{-LT}$ by 44%, and relative $\text{VO}_2\text{-LT}$ by 15%. The subjects' $\text{VO}_{2\text{max}}$ increased 25%, and maximum workload increased 28%. Exercise intensities during training were at a HR corresponding to 50% between LT and $\text{VO}_{2\text{max}}$ (first 4 weeks), then progressed to intensities of 70% between LT and $\text{VO}_{2\text{max}}$ for the remaining 5 weeks. Following training, LT occurred at 57% $\text{VO}_{2\text{max}}$ as compared to only 49% $\text{VO}_{2\text{max}}$ before training.

Similar findings were reported for the group of IHDP studied by Coyle et al. (1983). Posttraining $\text{VO}_{2\text{max}}$ improved 42% by training at 70% to 90% $\text{VO}_{2\text{max}}$. However, the occurrence of LT at 100% $\text{VO}_{2\text{max}}$ indicated that submaximal endurance capacities most likely improved more than $\text{VO}_{2\text{max}}$. Unfortunately, pretraining LT was not determined in either group. Nevertheless, LT for the untrained patient control group occurred at only 67% $\text{VO}_{2\text{max}}$, which supported the theory that significant improvements in LT were influenced by training (Coyle et al., 1983).

Coyle et al. (1983) attributed the unusually high LT to greater skeletal muscle oxidative adaptations when $\text{VO}_{2\text{max}}$ is limited by impaired heart function. This conclusion was supported by findings of similar, and even lower lactate levels at the same velocities in IHDP as in healthy performance-matched subjects. This implied that both had the similar peripheral respiratory capacities. Ivy and associates (1980)

concluded with these findings. They observed a high correlation between LT and muscle respiratory capacity. It was concluded that peripheral metabolic and vascular adaptations are critical in delaying the onset of blood lactic acid, and may be independent of central hemodynamics.

Runners trained at or above LT displayed significant peripheral metabolic changes without changes in maximal oxygen consumption (Acevedo & Goldfarb, 1989; Daniels, Yarbrough, & Foster, 1978; Henritze et al., 1985; Sjodin et al., 1982). Hagberg (1984) suggested that $\text{VO}_{2\text{max}}$ is more dependent on central cardiovascular factors, while changes in LT are more related to peripheral metabolic changes in skeletal muscle, especially enzyme activity. Sjodin and colleagues (1982) demonstrated that training at an intensity corresponding to $4.0 \text{ mmol}\cdot\text{l}^{-1}$ one time per week for 20 minutes significantly increased VEL-OBLA $4.0 \text{ mmol}\cdot\text{l}^{-1}$. This training session lasted 14 weeks and was incorporated into the runner's normal training program. It was believed that changes were the result of increased skeletal muscle enzyme activity, capillary density, and running economy. The latter was confirmed by a decrease in VO_2 while running at $15 \text{ km}\cdot\text{h}^{-1}$ in the same group of runners.

The improved running economy noted by Sjodin and colleagues (1982) correlated with an increase in heart specific lactate dehydrogenase (H-LDH) activity ($r = -.75$) which indicated enhanced ability of the cells to oxidize lactate. The activity of phosphofructokinase (PFK) and the PFK:CS (citrate synthase) ratio also decreased substantially after training. They noted that the longer distance runners exhibited an increase in CS activity (+22%) while the 800 m specialists displayed a decrease in CS activity (-13%). In addition, the decrease in PFK

activity in the middle distance was greater than the long distance runners after training (50% versus 21% decrease, respectively). Consequently, the PFK:CS ratio was reduced overall, suggesting the rate of glycogenolysis decreased during exercise. This in turn increased the ability of the skeletal muscles to oxidize pyruvate and lactate. Recent observed decreased rates of glycogen utilization at the same workloads following training (MacRae et al., 1990).

The action of the heart-specific form of lactic dehydrogenase (H-LDH) in the mitochondrion minimizes lactate production when NAD is present (Sjodin & Jacobs, 1981). This enzyme has been shown to be favored in ST fibers (Costill, 1986; Tesch et al., 1981). In support of this, a significant relationship was demonstrated between %ST fibers and changes in VEL-OBLA $4.0 \text{ mmol} \cdot \text{l}^{-1}$ following training [$r = .83$] (Sjodin et al., 1982). Daniels et al. (1978) emphasized the importance of examining variables related to peripheral metabolic factors in skeletal muscle when assessing the adaptations resulting from training. Sjodin and associates (1982) suggested that VEL-OBLA $4.0 \text{ mmol} \cdot \text{l}^{-1}$ is "a more sensitive parameter for the monitoring of adaptations to training than is the determination of $\text{VO}_{2\text{max}}$."

Recent studies confirm this conclusion. Kohrt et al. (1989) conducted a longitudinal study examining training effects in triathletes. The most significant finding was that running $\text{VO}_{2\text{max}}$ did not increase during the training season, while $\text{VO}_{2\text{-LT}}$ increased significantly (6%), from 47.0 to 50.0 ($\text{l} \cdot \text{min}^{-1}$). Relative VO_2 ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) also increased, from 80 to 85% $\text{VO}_{2\text{max}}$. Cycling $\text{VO}_{2\text{-LT}}$ increased by 10% (72 to 76% $\text{VO}_{2\text{max}}$) while $\text{VO}_{2\text{max}}$ increased only 5%. The

lower mean LT in cycling was attributed to a higher training volume in running as compared to cycling. In addition, several of triathletes were exclusively runners prior to becoming triathletes, and trained more in this activity. The same conclusion was applied to the swimming values observed, as LT and VO_{2max} did not improve over the course of the training season. Kohrt and associates (1989) suggested that the key to improving triathlon performance, is to raise the LT in each event. To confirm this conclusion, Town and Tyll (1990) observed that elite triathletes are able to perform at very high percentages of VO_{2max} in all three events (79 to 87% VO_{2max}).

The variability in LT values in each triathlon event suggested that adaptations which influence improvements in LT are specific to the muscles involved in the exercise. Specificity of training and its effect on LT was recently studied in a group of sedentary males (Pierce et al., 1990). The run-trained group demonstrated a significantly greater increase in VO_{2-LT} (58.5%) compared to cycling VO_{2-LT} (20.3%). The cycling-trained group experienced significant changes in cycling VO_{2-LT} (38.7%) while running LT remained virtually unchanged (1.6%). The increase in both run and cycle LT observed in the run-trained group suggests an overlap in neuromuscular recruitment patterns during running and cycling.

Pierce et al. (1990) demonstrated that improvements in VO_{2-LT} and $VEL-LT$ appears to be specific to the mode of exercise. Triathletes studied by Kohrt and associates (1989) observed that VO_{2-LT} and $VEL-LT$ improved more in the activities emphasized during training. Swimming LT and VO_{2max} were unchanged over the season, indicating that running and

cycling had no "cross-training" effects which influenced swim performance. An earlier study on triathletes supported the specificity of training rule (Kohrt, Morgan, Bates, & Skinner, 1987). They observed that triathletes were well trained in all events, but not to the same level as single sport specialists.

Optimal Training Intensities

Recently it was demonstrated that training slightly above the IAT (or LT) will produce significant gains in LT (Jacobs, Keith, & McLellan, 1990; Keith & Jacobs, 1991). These investigators observed no differences in the magnitude of adaptations between exercising continuously for 30 minutes at the IAT, or exercising at 30% above and below the IAT in 7.5 minutes intervals. Significant improvements were observed in VO_2max , power output at IAT/LT, exercise time to exhaustion, and CS activity in the vastus lateralis muscle. These changes were similar to those reported by others who trained subjects above and below LT (Davis et al., 1979; Sady et al., 1980).

The significance of this report was that it took only 15 minutes of intervals slightly above LT to provide the same benefit as 30 minutes of continuous exercise above and below LT. Training slightly above LT most likely produces significant improvements in LT because more fast twitch "b" (FTb) muscle fibers are recruited. The increase in VEL-LT is therefore the result of an enhanced FTb oxidative capacity brought on by the stimulus of higher intensity training.

As demonstrated, the type of training session (interval versus continuous) conducted at these intensities did not seem to be a critical factor for LT enhancement. Instead, higher intensity was the critical

factor that brought about the changes. In trained runners, Acevedo and Goldfarb (1989) observed significant decreases in plasma lactate concentrations at 85% and 95% $\text{VO}_{2\text{max}}$ after increased intensity training (IIT). The training program consisted of 8 weeks of IIT, with 1 day of intervals at 90% to 95% HR_{max} , and two fartlek runs at slightly below and above 10 km pace, both of which were above LT. Their normal weekly training mileage did not increase, only intensity. No change in $\text{VO}_{2\text{max}}$ was observed, while 10 km time decreased by one minute, and run time to exhaustion increased four minutes. This was a 20% increase from pretraining.

It is apparent that various types of training sessions conducted at higher intensities can improve performance factors relating to LT. These findings confirm that intensity is the primary determinant for improvements in LT.

Maximal Lactate Steady State

A maximal lactate steady state (MLSS) exists when there is maximal balance between lactate production and elimination which corresponds to a certain workload. Heck and associates (1985) demonstrated that a MLSS corresponded to a mean lactate concentration of $4.02 \text{ mmol}\cdot\text{l}^{-1}$. Although, a wide variance in lactate concentrations were observed, ranging from 3.05 to 5.52. In contrast, lactate steady states were reached at approximately $3.0 \text{ mmol}\cdot\text{l}^{-1}$ in trained marathoners during 45 minute treadmill tests conducted at race pace (Fohrenbach et al., 1987). Stegmann et al. (1981) observed steady state lactate levels ranging from 1.4 to 7.5 in highly trained athletes. During treadmill running, mean lactate values at the IAT steady state were $2.1 \pm 0.5 \text{ mmol}\cdot\text{l}^{-1}$ for

runners, $3.91 \pm 1.1 \text{ mmol}\cdot\text{l}^{-1}$ for handball players, and 4.6 ± 1.2 for physical education students (Stegmann et al., 1981). Therefore, it appears that lactate steady states vary among sport specialists, and typically occurs lower than the $4.0 \text{ mmol}\cdot\text{l}^{-1}$ concentration.

Consequently, mean values based on heterogeneous samples may not provide an accurate assessment of the individual lactate kinetics.

A more recent study (Mognoni, Sirtori, Lorenzelli, & Cerretelli, 1990) observed similar findings as those reported by Heck et al. (1985). Using a very similar experimental protocol, lactate steady states were reached near $4 \text{ mmol}\cdot\text{l}^{-1}$. The range of values observed were also the same as in Heck et al. (1985), 3.0 to $5.3 \text{ mmol}\cdot\text{l}^{-1}$. This evidence suggests that the $4.0 \text{ mmol}\cdot\text{l}^{-1}$ concentration as representing the "true" MLSS would appear to apply only to group analysis.

The debate over the $4.0 \text{ mmol}\cdot\text{l}^{-1}$ originated from proponents who have demonstrated its validity as an optimal training index (Kindermann et al., 1979; Kohrt et al., 1989; Sjodin et al., 1982), and from those who caution its use as a universal training intensity (Martin & Coe, 1991; Oyono-Enguelle et al., 1990). Martin and Coe (1991) noted the potential for undertraining or overtraining when the $4.0 \text{ mmol}\cdot\text{l}^{-1}$ index is used in training. The latter may be especially true for endurance trained runners who typically have a MLSS below $4.0 \text{ mmol}\cdot\text{l}^{-1}$ (Chwalbinska-Moneta et al., 1989; Farrell et al., 1979; Fohrenbach et al., 1987; Iwaka, Fuchi et al., 1988; Stegmann & Kindermann, 1982). However, Martin and Coe (1991) do support the use of the $4.0 \text{ mmol}\cdot\text{l}^{-1}$ lactate concentration in general training, but only for specific high intensity training sessions, which make up only a small percentage of a runner's total

weekly mileage.

Individual Anaerobic Threshold

Recently, studies have endorsed the concept of the IAT, and defined it as the "highest metabolic rate at which BLA concentrations can be maintained at a steady-state during prolonged running" (Jacobs et al; 1990; Keith & Jacobs, 1991; McLellan & Cheung, 1991). More specifically, it was defined as "the work load corresponding to the steady state between the diffusion of lactate into the blood compartment and maximal elimination from the blood and muscle compartments" (Stegmann & Kindermann, 1982). The theoretical basis of the IAT attenuates the concept of the $4.0 \text{ mmol} \cdot \text{l}^{-1}$ lactate concentration as the MLSS, but coincides with the concept of the LT, as both attempt to identify "thresholds" based on individual lactate kinetics.

The $4.0 \text{ mmol} \cdot \text{l}^{-1}$ lactate concentration became a popular training threshold based on the assumption that it provided a similar training stimulus for endurance athletes. Only a modest correlation ($r = -.76$) was found between performance and the $4.0 \text{ mmol} \cdot \text{l}^{-1}$ lactate level (Lehmann et al., 1983). Stegmann and associates (1981) proposed that a better "threshold" intensity should be based on individual lactate kinetics in response to exercise. They suggested that the $4.0 \text{ mmol} \cdot \text{l}^{-1}$ lactate concentration does not take into account "the individual kinetics of the blood lactate curve." They demonstrated that the point of a rapid rise in lactate varies considerably among individuals, ranging from approximately 1.4 to $7.5 \text{ mmol} \cdot \text{l}^{-1}$. This individual inflection point was defined as the "Individual Anaerobic Threshold" (IAT). It was hypothesized that the workload at the IAT corresponds to a true maximal

lactate steady state for each individual.

Oyono-Enguelle et al. (1990) demonstrated that an equilibrium between the rate of appearance and disappearance of lactate may be difficult to detect from an incremental exercise test. This may be especially true with short stage duration tests, which may not allow observation of the transient decreases or increases that occur later in exercise (Oyono-Enguelle et al., 1990). However, these authors still endorse the use of individual lactate curves to obtain information on individual lactate responses to exercise.

Jacobs and colleagues (1990) supported the work of Oyono-Enguelle et al. (1990). They demonstrated that $\dot{V}O_2$ and BLA achieved steady states (i.e., no significant changes) at three different workloads corresponding to the IAT, and 20 Watts above and below the IAT. Based on these findings, these authors concluded that the IAT protocol be "re-examined to ensure that the highest intensity eliciting a lactate steady state can be determined" (Jacobs et al., 1990).

Summary

It is evident that strong relationships exists between BLA parameters and performance. Prediction equations based on this premise could, therefore, be an important training tool for both endurance athlete and coach. However, methodology employed in the detection of BLA parameters still remains controversial and requires standardization. Most of the recent evidence strongly supported the concept that individual lactate kinetics provide the most accurate and precise information concerning BLA concentrations in response to exercise. Therefore, knowledge of this information has significant implications

for endurance sport conditioning and performance forecasting.

CHAPTER III

METHODS

Introduction

In this study the direct measurements of oxygen consumption (VO_2), velocity (VEL), heart rate (HR), and blood lactate (BLa) were obtained during physiological tests involving horizontal treadmill running. Predicted values for LT and FBLO were based on a 3200 m run performance time conducted on an indoor 220 yard track. This chapter presents the specific methodology utilized for subject selection and orientation, measurement of the above variables, and statistical analysis of the results.

Subject Selection

Twenty-seven endurance trained male subjects from the University of Wisconsin-La Crosse and from the community of La Crosse, Wisconsin, were asked to volunteer in this study. The majority of subjects were members of the University of Wisconsin-La Crosse Men's Cross Country Team and Track Team. Others included runners from local running and triathlon clubs who met the specified criteria. Prior to testing, each subject signed an informed consent, which described the testing procedures and potential risks involved (see Appendix A).

Development of Instrumentation

Gas Analysis

Throughout the VO_2 peak test, gas analysis was performed breath by

breath using a Q-Plex I Cardiopulmonary Exercise System (Quinton Instruments Company). The Q-Plex was calibrated before and after each test to known percentages of oxygen and carbon dioxide, previously validated by Scholander technique. The Q-plex was also calibrated to ambient air temperature, barometric pressure, and relative humidity. Barometric pressure and air temperature were read from a mercury barometer and thermometer located in the testing area. Relative humidity was determined by differences in wet and dry bulb temperatures.

Subjects wore a headgear with a mouthpiece attached to nonrebreathing Rudolph valve and a noseclip. Expired gases were directed into the mixing chamber of the Q-Plex and subsequently analyzed for absolute and relative oxygen content. In addition to $\dot{V}O_2$, the following gas parameters were measured: expired carbon dioxide ($\dot{V}CO_2$), minute ventilation ($\dot{V}E$), respiratory exchange ratio (R), fraction of expired carbon dioxide ($FECO_2$), and fraction of expired oxygen (FEO_2). All gas parameters were calculated by the Q-Plex for 1 minute time periods. The gas exchange data utilized in the results were those measured during the last minute of each exercise stage.

Blood Lactate Concentrations

Total BLA concentrations (extracellular and erythrocytes) were measured by an automated lactate analyzer (Yellow Springs Instrument Company, Model 23L). The BLA values expressed in $\text{mmol}\cdot\text{l}^{-1}$ were displayed within 45 seconds on the analyzer's digital readout panel following injection of a 25 microliter (μl) blood sample. A 25 μl syringepet (Yellow Springs Instrument Company) was used to inject each 25 microliter blood sample. In this study, the readings on the YSI display

were multiplied by three to account for the 3:1 dilution of the blood sample. The treatment and handling of the blood sample is explained in the following section, and in Appendix B.

When a blood sample is injected into the instrument, lactate diffuses through three enzyme-containing membranes attached to the end of an electronic cathode. Upon contact with the membranes, lactate is broken down by catabolic actions of the enzymes. This conversion of lactate produces substances which are electronically measured by the probe. The electric current produced is linearly proportional to the concentration of lactate in the blood sample (YSI Model 23L Instruction Manual).

Since the membrane integrity is vital to the validity and accuracy of the YSI Model 23L lactate analyzer, the membrane integrity was checked daily. Linearity, indicating good membrane integrity, generally lasted 5 to 7 days, but could handle an unlimited number of samples per day throughout the life of the membrane.

The instrument was calibrated and checked for linearity to known lactate standards (5.0 and $15.0 \text{ mmol} \cdot \text{l}^{-1}$) before each test, and after every two samples analyzed.

Previous investigations of the YSI assay of total BLA indicate it compares favorably ($r = .999$) with a known reference method (Boehringer Mannheim Corporation) which used photoenzymatic techniques (YSI model 23L Instruction Manual). In an independent study using highly trained athletes, similar results were found when comparing values measured with the YSI instrument and reference photoenzymatic methods ($r > .99$) (Van Handel et al., 1990).

Treatment of Blood Sample

In this study, treatment of the blood sample for analysis followed the same methodology as that used by Van Handel and coworkers (1990) of the United States Olympic Training Center in Colorado Springs, Colorado (see Appendix B). Each 25 μ l blood sample was expelled into a microcentrifuge tube containing 50 μ l of the following: Buffer Solution (Yellow Springs Instrument Company 7g), Triton X-100, (Octyl Phenoxy Polyethoxyethanol; Sigma Chemical Company, T-6878), and Sodium Fluoride (NaF anhydrous, molecular weight - 42.0; Sigma Chemical Company, S-1504). Eleven pairs of tubes (for duplicate analyses) of the NaF-Triton buffer were prepared in advance for each test and capped to prevent evaporation.

The Triton X-100 is a substance which lyses the red blood cells, and, therefore, allows both intracellular and extracellular lactate to be measured. Sodium fluoride inhibits the glycolytic reactions of the red blood cell, therefore preventing further increases in lactate concentrations. Even though controversy still exists, it has been suggested that measuring total BLa during steady-state exercise is more reflective of the metabolic state of the contracting muscle. In theory, the time required to reach a physiological steady-state in exercise will result in an equilibrium between blood and muscle lactate. Therefore, total BLa would seem to be the preferred measurement.

Heart Rate

Radio telemetry HR monitors (UNIQ Heart Watch, model 8799, Computer Instrument Corporation) were used to determine HR during the $\dot{V}O_2$ peak test. Two receivers were used in case of equipment failure. To

avoid electrical interference, the receivers were attached to the treadmill handrail opposite the Q-Plex.

The HR was continuously monitored throughout the VO_2 peak test, and entered into the Q-Plex microcomputer every minute. The HR monitor's memory program was used to store HR every 15 seconds during each test to confirm HR values.

Treadmill Speed and Grade

A pit-style treadmill (Quinton Instruments, Model 24-72) was used for the VO_2 peak test. Speeds (expressed in miles per hour), and grade (expressed in per cent) were indicated by needle gauges on the treadmill control box. Speed and grade were set by controls on the control box.

For this study the treadmill was kept at a 1% grade throughout the VO_2 peak test. This procedure was based on research conducted by Heck and coworkers (1985). Their studies indicated that treadmill running with grades between 0% and 2% elicited similar physiological responses as running on solid ground, a cinder track, or an artificially surfaced track. Following their recommendations, a 1% grade was used to allow for maximum transference to field settings.

Performance Time

Performance time was determined to 1/100 of a second by hand held electronic stop watches (Fisher Scientific).

Lactate Threshold Identification

The LT was identified as the highest VEL achieved without an increase in lactate concentration above a baseline associated with low levels of exercise intensity. This value was designated as the VEL associated with LT (Vel-LT). The VO_2 and HR associated with this VEL

were designated as VO_2 -LT and HR-LT respectively.

To avoid under or overestimating the LT, the percentage of VO_{2peak} and HRpeak were taken into consideration when identifying the baseline and LT. Evidence from previous studies indicated that LT in well trained runners typically occurs from 80% to 86% VO_{2peak} , or approximately 90% of HRmax (Costill, 1986; Martin & Coe, 1990). These criteria were used only as guidelines to aid in LT identification by visual inspection of the individual lactate curves. Use of these criteria were especially useful when a distinct BLA inflection point was not apparent, or when more than one inflection point resulted. Due to the individual variability of BLA response to exercise, both of these preceding conditions were expected to occur in a number of subjects.

Determining VO_2 , VEL, and HR at FBLC

To determine oxygen consumption at 2.0, 2.5, and 4.0 $mmol \cdot l^{-1}$, each VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) and BLA concentration ($mmol \cdot l^{-1}$) were first transformed into log values. If the LT occurred at or below 2.0 $mmol \cdot l^{-1}$, linear regression of the log data was applied to only the data points from the LT to VO_2 peak (i.e., the upper region of the lactate curve). If the LT occurred above 2.0 $mmol \cdot l^{-1}$, then regression was applied to the transformed data for both the lower and the upper region of the lactate curve. The LT was included in the regression of both sets of data.

Using the equations generated from linear regression of the Log-BLA to Log- VO_2 relationship, the log values for 2.0, 2.5, and 4.0 $mmol \cdot l^{-1}$ were used to compute the corresponding log values for VO_2 . The estimated VO_2 in $ml \cdot kg^{-1} \cdot min^{-1}$ was determined by taking the inverse of Log- VO_2 .

With VO_2 at 2.0, 2.5, and 4.0 $\text{mmol}\cdot\text{l}^{-1}$ identified, velocities and HR at 2.0, 2.2, and 4.0 $\text{mmol}\cdot\text{l}^{-1}$ were determined by regression analysis based on the linear relationship between VO_2 , HR, and VEL. Nonparametric statistics were used to generate the equations used for the preceding regression analysis of the individual data sets.

Computing Predicted Values

Performance times from the 3200 m time trial were used to calculate predicted values for VEL in $\text{m}\cdot\text{min}^{-1}$ and VO_2 in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ at LT, FBLO of 2.0, 2.5, 4.0 $\text{mmol}\cdot\text{l}^{-1}$, and peak using the following equations (Weltman et al., 1987, page 403):

VO_2 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ corresponding to:

$$\begin{aligned}\text{LT} &= 111.5 - 5.200 (3200\text{-m time, min}) \\ 2.0 \text{ mmol}\cdot\text{l}^{-1} &= 118.8 - 4.867 (3200\text{-m time, min}) \\ 2.5 \text{ mmol}\cdot\text{l}^{-1} &= 108.5 - 4.432 (3200\text{-m time, min}) \\ 4.0 \text{ mmol}\cdot\text{l}^{-1} &= 122.0 - 5.310 (3200\text{-m time, min}) \\ \text{Peak} &= 118.4 - 4.770 (3200\text{-m time, min})\end{aligned}$$

Velocity $\text{m}\cdot\text{min}^{-1}$ corresponding to:

$$\begin{aligned}\text{LT} &= 493.0 - 22.78 (3200\text{-m time, min}) \\ 2.0 \text{ mmol}\cdot\text{l}^{-1} &= 497.3 - 21.56 (3200\text{-m time, min}) \\ 2.5 \text{ mmol}\cdot\text{l}^{-1} &= 504.4 - 21.54 (3200\text{-m time, min}) \\ 4.0 \text{ mmol}\cdot\text{l}^{-1} &= 509.5 - 20.82 (3200\text{-m time, min}) \\ \text{Peak} &= 498.0 - 18.84 (3200\text{-m time, min})\end{aligned}$$

Laboratory Testing Procedures

Subject Orientation

Prior to reporting to the laboratory for the VO_2 peak/LT test, subjects were asked to abstain from exercise for at least 24 hours preceding the test (McArdle, Katch, & Pechar, 1973; Stamford, Rowland, & Moffatt, 1978). They were also asked to abstain from caffeine containing beverages, alcohol, drugs, smoking or nicotine in other forms such as smokeless tobacco, large meals at least 4 to 6 hours before the test, and to be well rested. Subjects were also informed of the objectives of the test, procedures, equipment and apparatus used, and overall expectations. This was to promote consistency and efficiency between tests, and to reduce test anxiety (Hammond & Froelicher, 1984). This information was provided to each subject upon volunteering for the study.

In the days prior to testing, subjects reported to the laboratory for a 10 to 15 minute treadmill running practice. Following a demonstration, subjects practiced the technique for getting on and off the treadmill while it was moving. Speed was progressively increased to near their maximal speed for a very brief time to simulate the conditions of the VO_2 peak/LT test. Blood sampling procedures and test protocol were reviewed, including an explanation of a categorical ratings of perceived exertion (RPE) scale (Borg, 1978).

VO_2 peak/LT Test

Upon reporting to the laboratory for the VO_2 peak/LT test, a blood sample was taken from each subject to determine a resting lactate level. These preexercise lactate levels were used to indicate that lactate

levels were not elevated before the start of the test. Subjects were then allowed to warmup on the treadmill for 5 minutes. The warmup involved running at an easy pace which was subjectively determined by the subject. Warming up prior to exercise testing has been shown to result in higher maximum HR, higher VO_2 and muscle temperatures, and lower lactate levels when compared to tests with no warmup (Martin, Robinson, Wiegman, & Aulick, 1975). Following the warmup, subjects were encouraged to stretch and to drink at least 4 ounces of water (open to subject discretion) to prevent dehydration.

Initial treadmill velocity was set at 8.0 mph^{-1} ($214.4 \text{ m} \cdot \text{min}^{-1}$; 7 min:30 sec per mile [7:30 pace]), then increased 0.5 mph^{-1} ($13.4 \text{ m} \cdot \text{min}^{-1}$) at the end of every 3 minute stage until volitional exhaustion. VO_2 peak was chosen as the highest oxygen uptake ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) achieved during a 1 minute time interval during the test (McConnell, 1988; Weltman et al., 1990). Velocity peak (VELpeak) and heart rate peak (HRpeak) were chosen as the highest values achieved during a 3 minute time interval during the test.

Heart rate was monitored continuously throughout the test and entered into the Q-Plex microcomputer every minute. The RPE was obtained and also entered into the Q-Plex at the end of each 3 minute stage up to and including indication of level 17. From that level and on, RPE was obtained every minute until test termination. Verbal encouragement was provided throughout the test. Upon completion of the test, subjects recovered by running at a slow pace, or by walking.

Blood Sampling

Blood samples were collected by finger-stick method at rest and immediately following (within 30 seconds) each 3 minute stage of the VO_2 peak/LT test. A 10 second countdown was given before the end of each stage, then the subjects stopped running by using the handrails to assist in placing their feet on the outside platform of the treadmill. They immediately held out their left hand, palm up. Any one of the three middle fingers was selected to obtain a blood sample. These fingers were alternated for each subsequent blood sample. The finger was wiped with an alcohol pad, then completely dried with a sterile gauze pad. This procedure was necessary to prevent contamination with the lactate present in sweat (Van Handel et al., 1990).

To ensure sufficient blood flow, the puncture was made near the finger tip as opposed to the pad of the finger. The finger puncture was made using a sterile lancet (Owen Mumford LTD Medical Division), and an autolet II (Owen Mumford LTD Medical Division). New lancets were used for each sample taken. To avoid additional contamination, the first drop of blood was wiped away. Then a sample was collected in a 50 μ l heparinized capillary tube which was completely filled to allow assay of duplicate samples. Caution was taken to avoid excessive squeezing, or "milking" the finger as this may have caused inaccurate lactate values. The subject resumed running at the new speed one minute after the end of each stage.

Treatment of Blood Sample

Using the YSI lactate analyzer pipet, 25 micro liters (μ l) of blood were extracted from the capillary tube and expelled into a

microcentrifuge tube containing the 50 μ l NaF-Triton buffer. The prepared samples were immediately shaken for approximately 5 second to allow mixing. Following the test, the samples were kept refrigerated until assay, which was completed the same day.

To analyze each blood sample, 25 μ l of the sample was extracted from the microcentrifuge tube and expelled into the lactate analyzer for the measurement of BLA concentration. The lactate analyzer was zeroed and calibrated to a 5.0 $\text{mmol}\cdot\text{l}^{-1}$ lactate standard after every two samples analyzed.

3200 Meter Run

Upon reporting to the indoor 220 yard track, subjects were encouraged to warmup for at least 10 minutes before their time trial. To encourage competitive running, the subjects ran in groups arranged according to their respective competitive levels. The University of Wisconsin-LaCrosse men's distance track coach assisted with these groupings. Split times were provided every 400 ms, including lap count and verbal encouragement throughout the run.

Statistical Analysis

Student's dependent t-tests and regression analyses were used to compare the differences between actual and predicted values for VO_2 and VEL associated with LT, and FBLO of 2.0, 2.5, and 4.0 $\text{mmol}\cdot\text{l}^{-1}$, and peak. Regression analyses were also used to determine the ability of predicting the BLA parameters and peak values from a 3200 m performance time.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

This section examines the validity of the equations developed by Weltman et al. (1987) by comparing predicted versus actual measurements observed during the $\text{VO}_{2\text{peak}}$ test and as calculated from 3200 m performance times. In addition, the physiological variables associated with BLA parameters, and their relationship to performance are examined. Further discussion centers around differences in methodology which may have influenced the results, including the affects of homogeneity. Finally, the role of BLA in exercise prescription and training is examined, with special emphasis on the individuality reflected in BLA measurements during exercise and how this can be applied to training.

Descriptive Characteristics

As a group, the subjects in the present study were younger (- 9.7 years), weighed slightly less (- 2.5 kg), but were similar in height to the subjects in Weltman et al. (1987) [see Table 1]. The mean weight and height of the subjects in the present study are similar to those of highly trained distance runners (Farrell et al., 1979; Noakes et al., 1990; Tanaka et al., 1985). The relatively low standard deviations (SD) for age, weight, and height indicate homogeneity among subjects for these variables.

Table 1. Descriptive characteristics of male runners

Variable	Present Study (N = 27) mean $\pm$ SD	Weltman et al. (1987) (N = 29) mean $\pm$ SD
Age (yrs)	22.5 $\pm$ 5.2	32.2 $\pm$ 7.7
Weight (kg)	67.0 $\pm$ 5.8	69.5 $\pm$ 8.8
Height (cm)	177.0 $\pm$ 6.3	176.7 $\pm$ 4.9

Note. The data in column 3 are from "Prediction of lactate threshold and fixed blood lactate concentrations from 3200-m running performance in male runners", by A. Weltman et al. (1987).

Physiological Characteristics: $\text{VO}_2\text{Peak/LT}$ Test

The values observed during the $\text{VO}_2\text{peak/LT}$ test are presented in Table 2. The relative VO_2peak of $69.3 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ is similar to that of highly trained distance runners (Costill, 1986; Farrell et al. 1979; Lehmann et al., 1893; Martin & Coe, 1991 Noakes et al., 1990). Individual VO_2peak values ranged from $61.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ to a high of $77.5 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Four subjects achieved values above $75.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, which are within the range reported for elite runners (Martin & Coe, 1991; Costill, 1986). The subjects in Weltman et al. (1987) were not as highly trained as the subjects in the present study as indicated by a lower VO_2peak and 3200 m RT. In addition, both VO_2 and VEL corresponding to LT, FBLO of 2.0, 2.5, 4.0 $\text{mmol} \cdot \text{l}^{-1}$, and peak values were higher than those reported by Weltman et al. (1987) [see Table 2].

Heart rates were also consistently higher for the subjects in the present study. This can be attributed to the age difference between subject groups.

Table 2. VO_2 , VEL, and HR observed during $\text{VO}_{2\text{peak/LT}}$ test, and 3200 m time

Variable	Present Study (N = 27) mean $\pm$ SD	Weltman et al. (1987) (N = 29) mean $\pm$ SD
VO_2 ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)		
LT	58.5 $\pm$ 4.2	53.0 $\pm$ 6.7
2.0	58.4 $\pm$ 4.7	57.1 $\pm$ 6.5
2.5	60.7 $\pm$ 4.4	58.7 $\pm$ 5.9
4.0	65.1 $\pm$ 4.8	62.3 $\pm$ 6.7
Peak	69.3 $\pm$ 5.1	64.8 $\pm$ 6.5
Velocity ($\text{m} \cdot \text{min}^{-1}$)		
LT	261.1 $\pm$ 19.1	236.9 $\pm$ 26.9
2.0	261.4 $\pm$ 22.0	254.9 $\pm$ 25.2
2.5	272.1 $\pm$ 19.7	262.2 $\pm$ 25.0
4.0	290.2 $\pm$ 18.1	275.4 $\pm$ 23.6
Peak	321.3 $\pm$ 14.8	286.2 $\pm$ 21.8
HR ($\text{b} \cdot \text{min}^{-1}$)		
LT	174.8 $\pm$ 8.9	163.9 $\pm$ 12.6
2.0	173.9 $\pm$ 7.9	172.2 $\pm$ 11.6
2.5	177.9 $\pm$ 7.9	175.4 $\pm$ 10.7
4.0	185.2 $\pm$ 8.5	181.0 $\pm$ 10.3
Peak	192.6 $\pm$ 8.7	185.5 $\pm$ 9.6
3200 m time (min)	10.3 $\pm$.61	11.2 $\pm$ 1.0

Note. The data in column 3 are from "Prediction of lactate threshold and fixed blood lactate concentrations from 3200-m running performance in male runners", by A. Weltman et al. (1987).

Percentages of Peak Values at LT and FBLC

The percentages of peak values at which LT and FBLC of 2.0, 2.5, and 4.0 mmol·l⁻¹ occurred are presented in Table 3. The LT at %VO₂peak,

Table 3. Percentages of VO₂peak, VELpeak, and HRpeak at LT, 2.0, 2.5, and 4.0 mmol·l⁻¹

Variable	Present Study (N = 27) mean ± SD	Weltman et al. (1987) (N = 29)
VO ₂ (ml·kg ⁻¹ ·min ⁻¹)		
LT	84.5 ± 3.4	81.8
2.0	84.4 ± 5.5	88.1
2.5	87.8 ± 4.4	90.6
4.0	93.9 ± 3.2	96.1
Velocity (m·min ⁻¹)		
LT	81.3 ± 3.3	82.8
2.0	81.4 ± 4.7	89.1
2.5	84.7 ± 3.7	91.6
4.0	90.4 ± 3.2	96.2
HR (b·min ⁻¹)		
LT	90.7 ± 2.1	88.4
2.0	90.3 ± 3.2	92.8
2.5	92.4 ± 2.4	94.6
4.0	96.1 ± 2.1	97.6

Note. The data in column 3 were calculated from "Prediction of lactate threshold and fixed blood lactate concentrations from 3200-m running performance in male runners", by A. Weltman et al. (1987).

%VELpeak, and %HRpeak occurred at intensities similar to those of highly trained runners (Iwoka et al., 1988; Lehmann et al., 1983; Martin & Coe, 1991; Svendsen & Sjodin, 1984). As shown in Table 3, the LT in the present study occurred at a higher %VO₂peak, and %HRpeak than reported by Weltman et al. (1987).

In contrast, the LT at %VELpeak was slightly lower than reported by Weltman et al. (1987). In addition, the %VO₂peak, %VELpeak and %HRpeak associated with FBLC of 2.0, 2.5, and 4.0 mmol·l⁻¹, including %VELpeak-LT, were all lower than those values observed by Weltman et al. (1987) [see Table 3]. These findings may be due to the influence of training state and/or methodological differences in testing.

Performance Time

The subjects completed the 3200 m time trial in a mean time of 10.3 ± .61 minutes (10 min & 18 sec), and ranged from 9.5 to 12.3 minutes. As indicated by the relatively low standard deviation, this group of runners were relatively homogeneous for this variable. In contrast, the subjects studied by Weltman et al. (1987) completed the time trial in 11.2 ± 1.0 minutes, 54 seconds slower than the subjects in the present study. Therefore, on the basis of performance time, the subjects in the present study were apparently more highly trained, and more homogeneous, than the subjects studied by Weltman et al. (1987).

Actual versus Predicted Scores

VO₂ at LT, FBLC, and Peak

The cross-validation data for the equations to predict VO₂ in ml·kg⁻¹·min⁻¹ corresponding to LT, FBLC of 2.0, 2.5, and 4.0 mmol·l⁻¹, and peak values are presented in Table 4.

Table 4. Cross-validation of equations to predict VO_2 and VEL at LT, FBLC of 2.0, 2.5, 4.0 $\text{mmol}\cdot\text{l}^{-1}$, and peak values from a 3200 m time trial

Variable	Actual Value mean $\pm$ SD	Predicted Value mean $\pm$ SD	Mean Diff.	r	SEE
VO_2 ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)					
LT	58.5 $\pm$ 4.2	58.2 $\pm$ 3.2*	0.3	.58**	3.5
2.0	58.4 $\pm$ 4.7	61.9 $\pm$ 3.0	3.5	.39	4.4
2.5	60.7 $\pm$ 4.4	63.1 $\pm$ 2.7	2.4	.46	4.0
4.0	65.1 $\pm$ 4.8	67.5 $\pm$ 3.2	2.4	.50**	4.2
Peak	69.3 $\pm$ 5.1	69.3 $\pm$ 3.3*	0.0	.31	4.9
Velocity ($\text{m}\cdot\text{min}^{-1}$)					
LT	261.1 $\pm$ 19.1	259.4 $\pm$ 13.9*	1.7	.69**	14.1
2.0	261.4 $\pm$ 22.0	276.2 $\pm$ 13.2	14.8	.50**	19.4
2.5	272.1 $\pm$ 19.7	283.5 $\pm$ 13.2	11.4	.58**	16.5
4.0	290.2 $\pm$ 18.1	296.0 $\pm$ 12.7	5.8	.62**	14.6
Peak	321.0 $\pm$ 14.8	304.8 $\pm$ 11.5	16.2	.65**	11.5

*No significant difference ($p \geq .05$)

**Significant correlation ($p \leq .01$)

No significant ($p \geq .05$) differences were found between predicted and actual scores for VO_2 -LT and VO_2 peak. The standard error of estimates (SEE) for these variables indicated that the equations for these variables provided reasonable estimates for practical application. As Table 5 illustrates, the percent of predictive error associated with VO_2 -LT and VO_2 peak were relatively small (5.9% and 6.8%, respectively)

and within appropriate ranges for use in practical settings.

Table 5. Correlation between 3200 m run time and VO_2 and VEL at LT, FBLC of 2.0, 2.5, and 4.0 $\text{mmol}\cdot\text{l}^{-1}$, and peak values

Variable	r	SEE	Percent prediction error
VO_2 ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)			
LT	-.58*	3.5	5.9
2.0	-.40	4.4	7.5
2.5	-.47	4.0	6.6
4.0	-.50*	4.2	6.5
Peak	-.40	4.7	6.8
Velocity ($\text{m}\cdot\text{min}^{-1}$)			
LT	-.69*	14.1	5.4
2.0	-.50*	19.4	7.4
2.5	-.58*	16.5	6.1
4.0	-.62*	14.6	5.3
Peak	-.65*	11.5	3.6

*Significant correlation ($p \leq .01$)

The SEE values for the same variables by Weltman et al. (1987) were 4.38 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (8.3%, VO_2 -LT) and 4.51 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (7.0%, VO_2 peak) for the validation group. A noteworthy finding was that the equation to predict VO_2 -LT was more accurate and precise for the subjects in the present study than for the both the validation and cross-validation group in Weltman et al. (1987).

Actual and predicted values for VO_2 at FBLC of 2.0, 2.5, and

4.0 mmol·l⁻¹ were significantly ($p \leq .01$) different in the present study. The SEE for these variables were again within appropriate ranges to consider for valid prediction. The percent of predictive error ranged from 6.5% to 7.8% ml·kg⁻¹·min⁻¹ (see Table 5) which were similar to those reported by Weltman et al. (1987).

The correlation coefficients (regression analysis of predicted versus scores) for the VO₂ data indicated rather poor relationships between predicted and actual scores (see Table 4). Significant ($p \leq .01$) relationships were observed for VO₂-LT and VO₂-4.0, but are considered too low for practical consideration.

Velocity at LT, FBLC, and Peak

The cross-validation for the equations to predict velocity in m·min⁻¹ corresponding to LT, FBLC of 2.0, 2.5, and 4.0 mmol·l⁻¹, and peak values are also presented in Table 4.

No significant ($p \geq .05$) difference was observed between actual and predicted VEL-LT. Significant ($p \leq .01$) differences were observed for VEL at FBLC 2.0, 2.5, and 4.0 mmol·l⁻¹. However, the SEE for each of these variables was too large to consider the corresponding equations valid for predicting training velocities. To illustrate, the SEE for VEL-2.0 of 19.4, which was the highest SEE for the data, represented a predictive error of 7.4%. This corresponds to ± 27.4 seconds per mile, or 6.85 seconds per 400 m. This large error would not be acceptable for competitive training purposes. The SEE for the other variables represented errors, in seconds per mile, ranging from ± 17.6 (VEL-4.0), ± 20.0 (VEL-LT), and ± 21.7 (VEL-2.0).

The smallest predictive error was associated with VELpeak (3.6%),

representing an error of only ± 10.8 seconds per mile, which may be acceptable for prescribing training velocities. However, even this error would be considered by some too large for training purposes.

The predictive errors for each VEL variable were within the same range as the predictive errors observed by Weltman et al. (1987) who concluded that the errors were small enough to consider the equations valid for use in exercise prescription. However, this investigator believes that predictions for velocity need to be more precise than what had been observed in this study and by Weltman et al. (1987).

In contrast, greater errors in predicting VO_2 values may not be as critical. This conclusion is supported by the findings that VO_2 is less related to performance and BLA parameters than is velocity (see Table 5).

The relationships between actual and predicted values for VEL corresponding to LT, FBLC of 2.0, 2.5, and 4.0 $\text{mmol}\cdot\text{l}^{-1}$, and peak were significant ($p \leq .01$), but still considered only modest. Again, homogeneity among the scores, as indicated by the SD for these variables, most likely contributed to these low, but significant correlations.

Relationship to 3200 Meter Performance

VO_2 at LT, FBLC, and Peak

The results showed that a 3200 m performance was only modestly related to VO_2 at LT, FBLC of 2.0, 2.5, 4.0 $\text{mmol}\cdot\text{l}^{-1}$, and peak. As Table 5 indicates, VO_2 -LT ($r = -.58$, $p \leq .01$) had the most significant relationship with performance. The VO_2 -4.0 was the only other variable that was significantly related to performance.

Note that the correlations and SEE for this group of data were almost identical to the correlations observed between actual and predicted values. The only variable which differed was VO_2peak (see Tables 4 & 5).

Velocity at LT, FBLC, and Peak

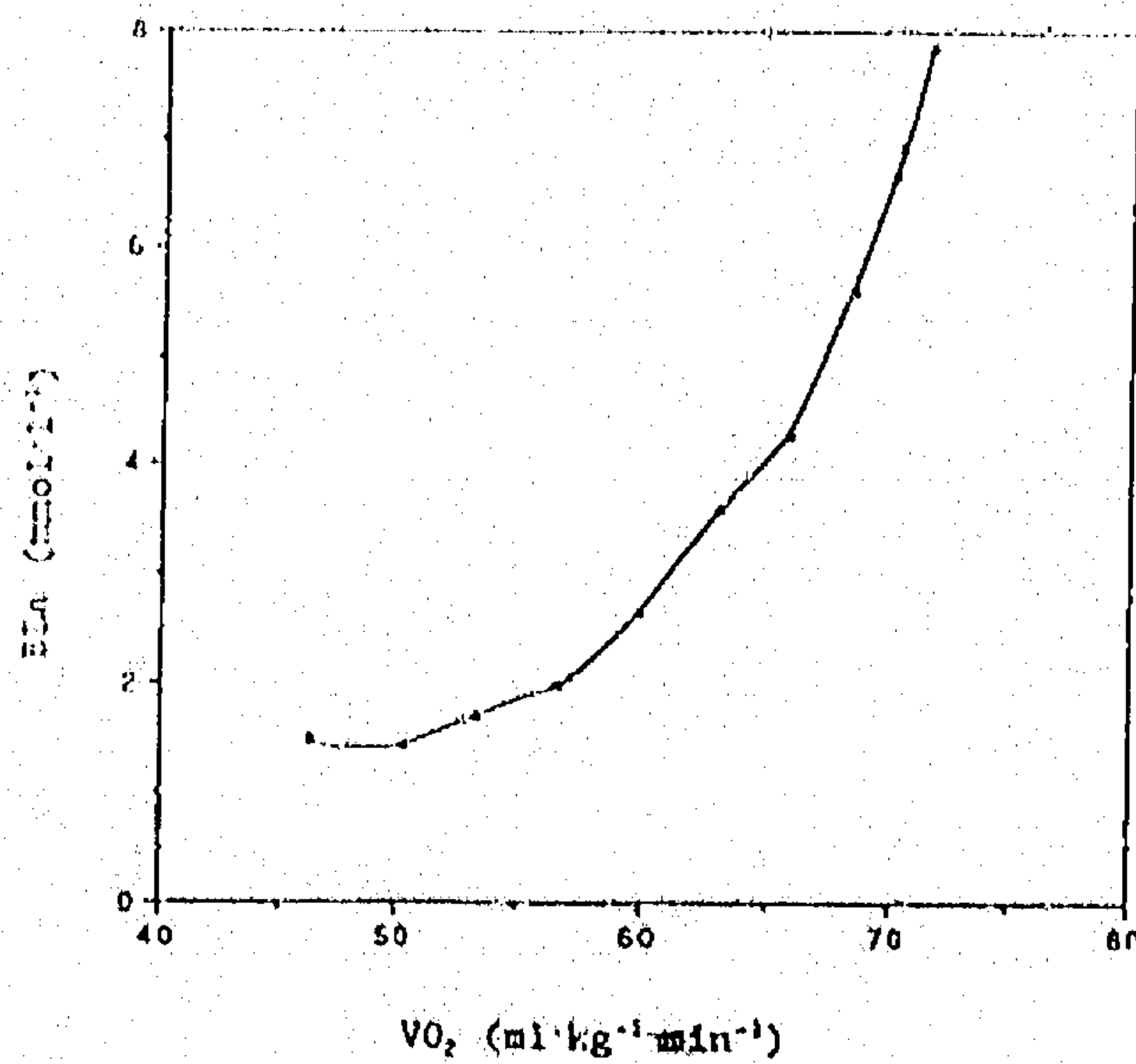
The results indicated that velocity corresponding to LT, FBLC, and peak was more highly related to performance than VO_2 (see Table 5). This coincides with the findings that several subjects with lower VO_2 values were still able to achieve higher velocities and faster run times than others with higher VO_2 values. The strongest relationship between any single variable and 3200 m RT was VEL-LT ($r = -.69$). Previous studies observed similar findings (Farrell et al., 1979; Kumagai et al., 1982; Noakes et al., 1990). These findings strongly support the use of the velocity associated with LT, FBLC, and peak in exercise prescription over the sole use of VO_2 indices for competitive endurance athletes.

Blood Lactate Accumulation Curves

Mean Blood Lactate Curve

The relationship between BLA and $\text{VO}_2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and velocity is shown in Figure 1. As indicated by the curves, BLA moderately increased up to stage four (each point on the curve represents a stage), at which time BLA increased abruptly at a concentration of $1.99 \text{ mmol} \cdot \text{l}^{-1}$. Each stage was 3 minutes with a $0.5 \text{ m} \cdot \text{h}^{-1}$ increase in velocity. This is within the range observed in other highly trained runners, which represents the $\text{VO}_2\text{-LT}$. Stegmann et al. (1981) observed a mean BLA value at the Individual Anaerobic Threshold (IAT) of $2.1 \text{ mmol} \cdot \text{l}^{-1}$ in trained runners. Others using total BLA determinations have reported mean BLA

a.



b.

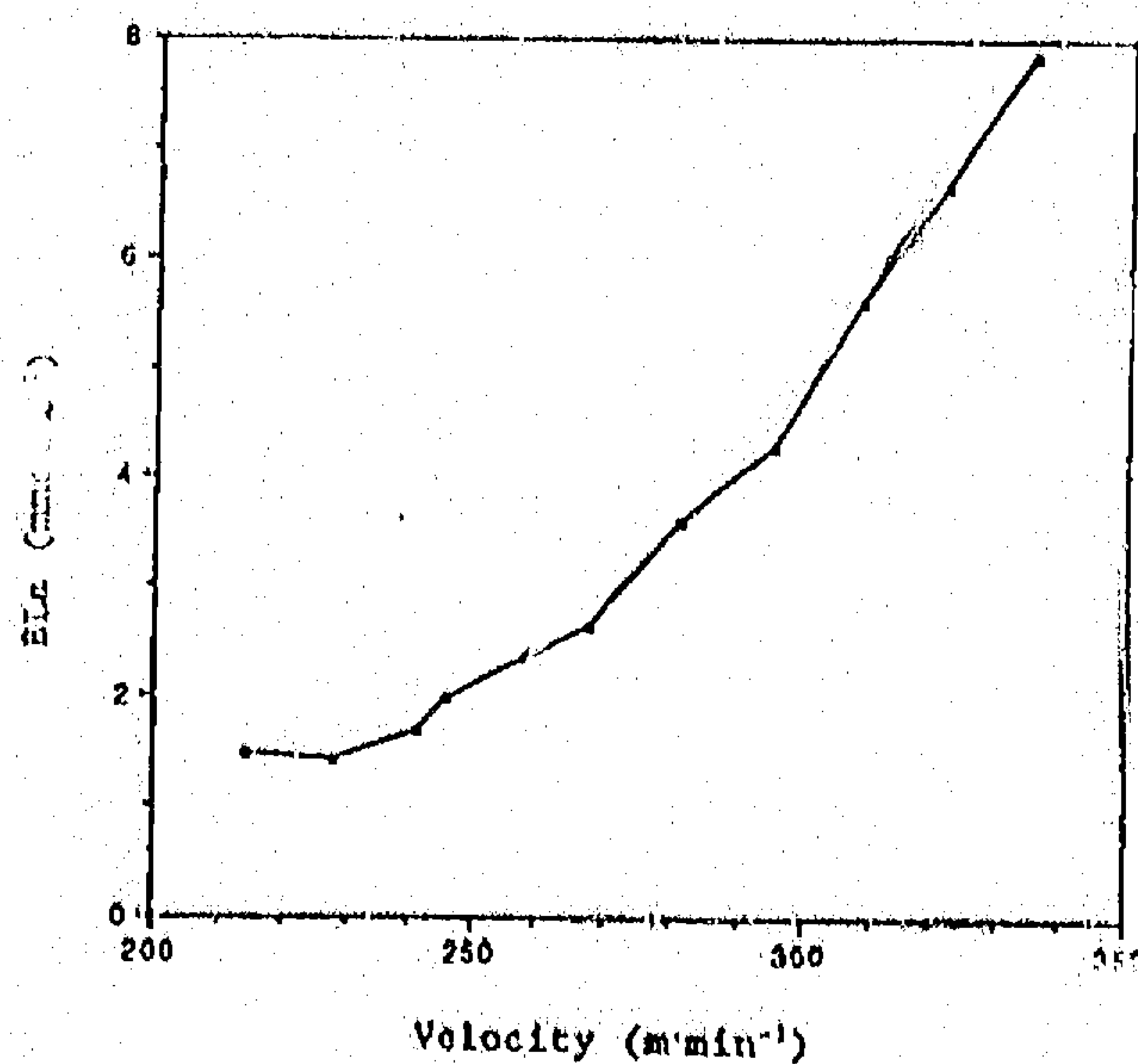


Figure 1. The relationship between BLA and VO₂ (a), and VEL (b) observed during the VO₂peak/LT test (derived from group means)

concentrations at LT ranging from 1.7 to 2.4 mmol·l⁻¹ in highly trained and elite caliber runners (Martin & Coe 1991). The BLA values at the LT in the present study ranged from 1.5 to 3.3 mmol·l⁻¹.

A graphical representation identifying the mean LT for the present group is shown in Figure 2.

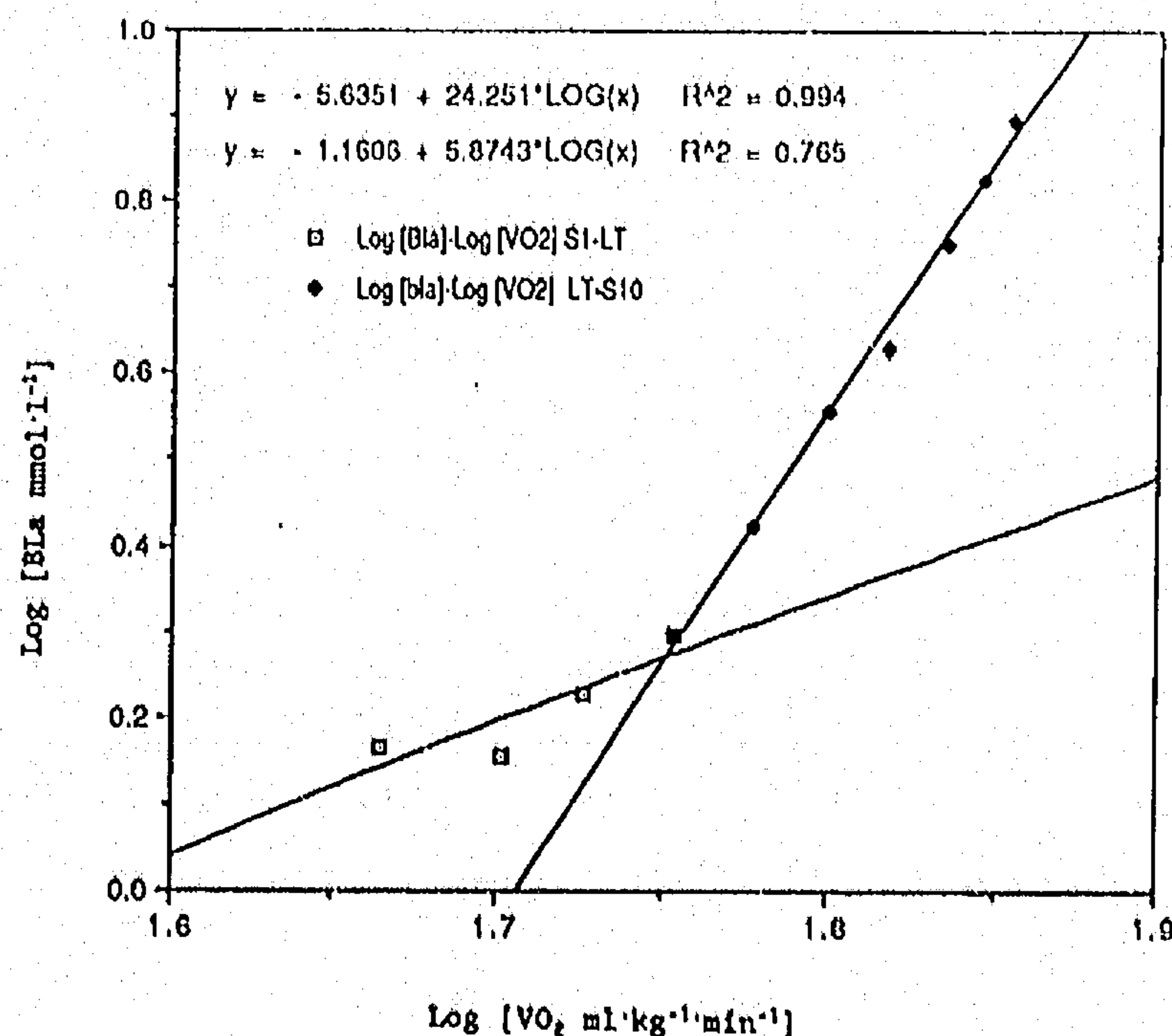


Figure 2. The relationship between BLA and VO₂ when both are expressed as log values. The VO₂ at the LT is represented by the intercept of the two lines (Note: S1-LT designates stage one through lactate threshold; LT-S10 designates lactate threshold through stage 10)

As described previously (Beaver et al., 1985), this method requires log transformations of VO₂ and BLA values, then applies linear

regression to the data points above and below the LT. The LT, identified by the intercept of the two lines, shows the LT occurring slightly below stage four, at approximately 84.5% $\dot{V}O_{2peak}$. The information from the BLA data provides only a general representation of the data and should, therefore, be used with caution when prescribing endurance training sessions. However, since the group tested was homogenous in demographic, physiological, and the performance variables, the mean data could be used as a general guide for training a similar group of runners. Ideally, however, information for exercise prescription utilizing BLA parameters should be based on data from individual lactate kinetics.

Individual Blood Lactate Curves

The individual variability in BLA response to incremental exercise is clearly evident in Figures 3 and 4. These curves represent the BLA response to incremental exercise of two subjects (A and B) who exhibited extremes in their observed values for $\dot{V}O_2$ and BLA parameters. The wide variability observed between these two subjects provides additional support for the use of individual BLA information for exercise prescription and training rather than group data.

To illustrate the variability BLA kinetics, Figure 4 shows that the LT for the same two runners (A and B) occurred at $250 \text{ m}\cdot\text{min}^{-1}$ (79% VEL_{peak}) and $281 \text{ m}\cdot\text{min}^{-1}$ (91% VEL_{peak}), respectively. Subject B was able to delay the onset of BLA accumulation until reaching a significantly faster velocity, and at a higher relative intensity based on $\dot{V}O_2$ kinetics (see Table 3). These results suggest that, compared to subject A, subject B should be able to maintain a faster submaximal running pace

for a longer period of time before fatigue impaired performance. Thus, in theory, subject B would be expected to out-perform subject A in distance races based on his BLA and VO_2 response to incremental exercise. As will be discussed, these findings have important implications for prescribing training programs based on individual BLA kinetics.

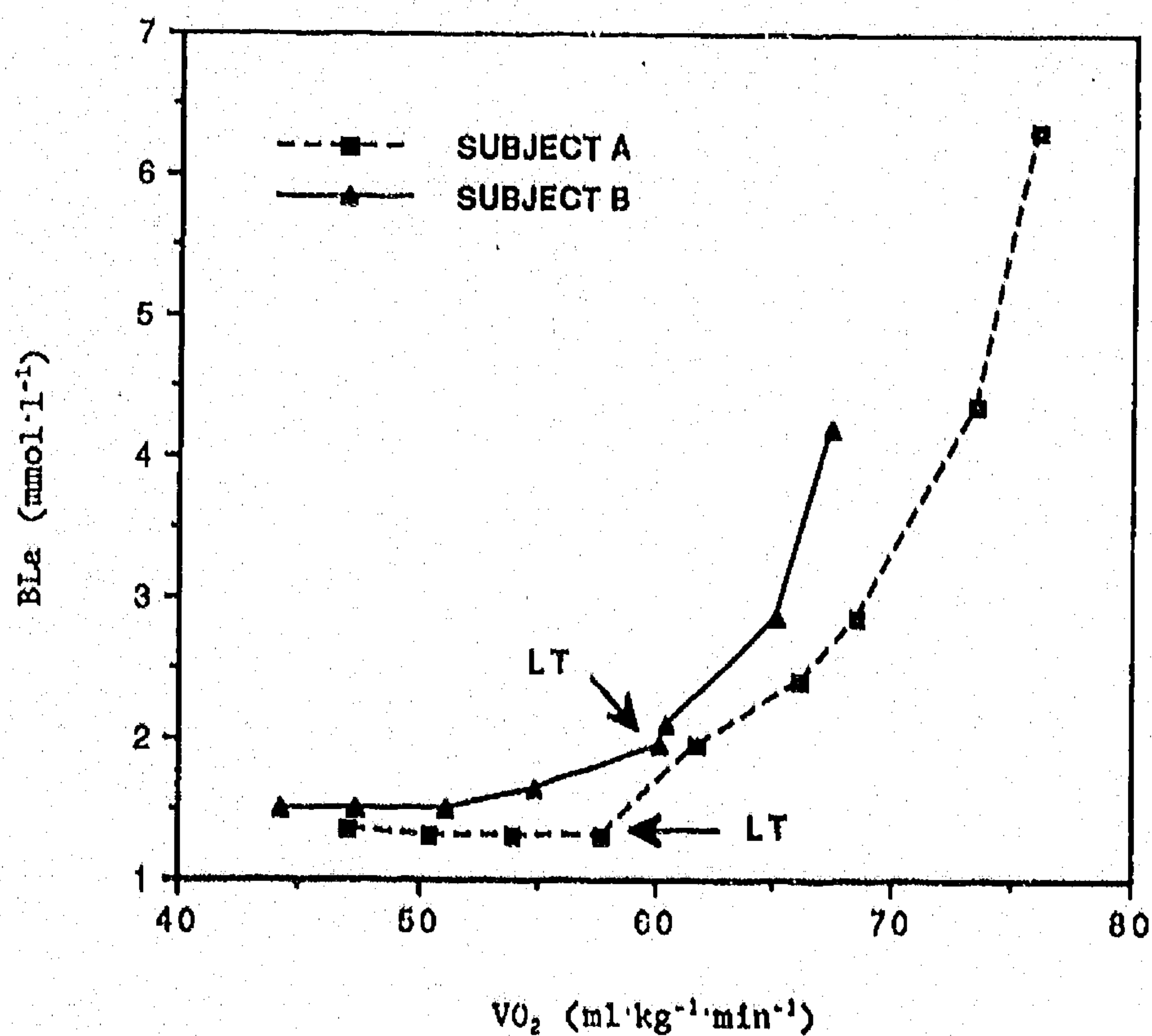


Figure 3. The relationship between VO_2 and BLA observed in two subjects during the incremental $\text{VO}_{2\text{peak}}/\text{LT}$ treadmill test.

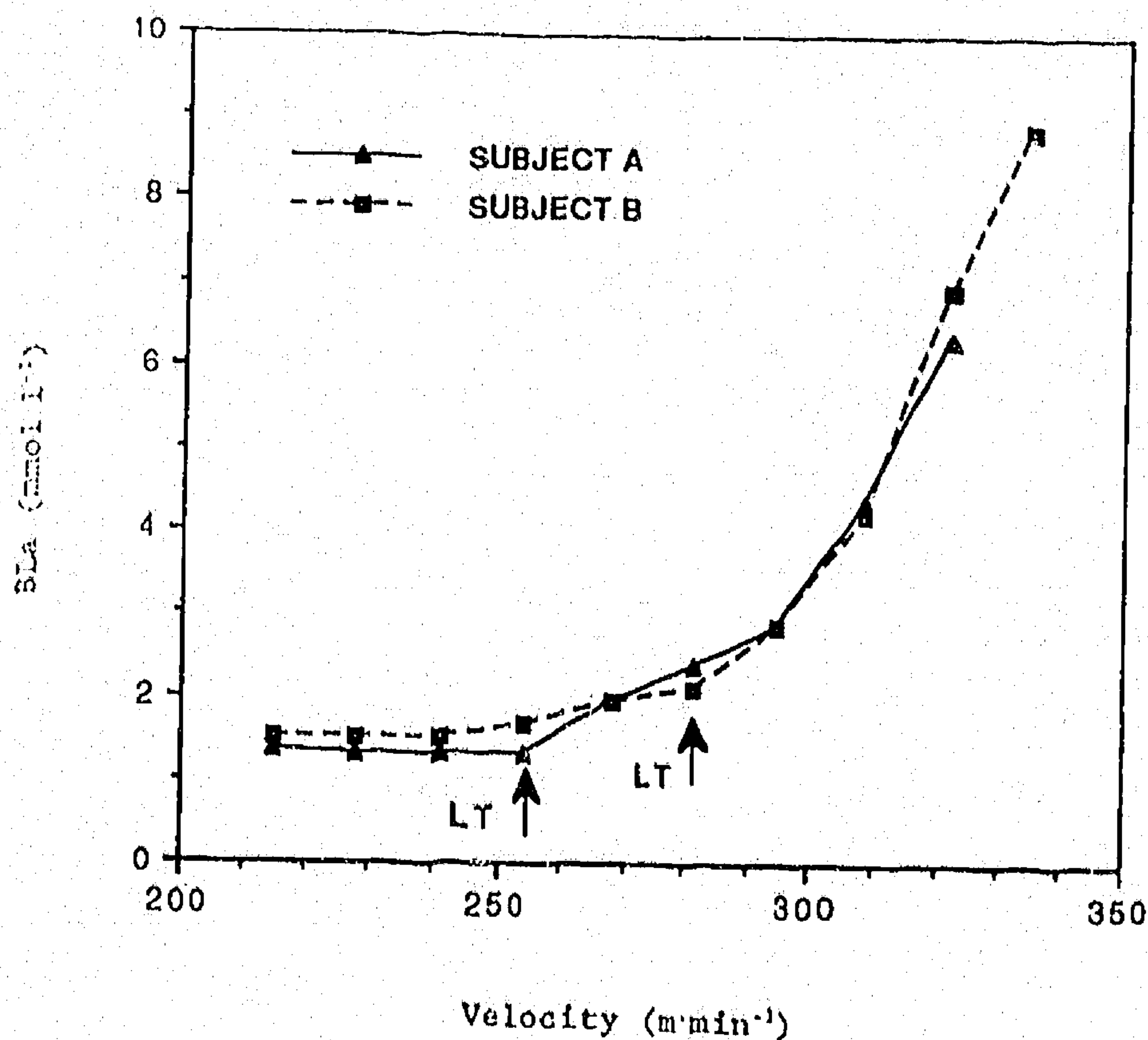


Figure 4. The relationship between running VEL and BLA observed in two subjects during the incremental $\text{VO}_{2\text{peak}}$ /LT treadmill test.

$\text{VO}_{2\text{peak}}$ and Test/Run Performance

A discussion regarding VO_2 and $\text{VO}_{2\text{peak}}$ values observed for these two subjects and the relationship to performance also deserves attention. These findings, while not representative of the entire group, do provide additional evidence to suggest that BLA parameters, not $\text{VO}_{2\text{peak}}$, is a better indicator of performance.

The VO_2 -LT for subject B occurred at $61.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (90% $\text{VO}_{2\text{peak}}$) compared to $57.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (76% $\text{VO}_{2\text{peak}}$) [see Figure 3]. As

indicated, subject B was able to achieve LT at a much higher relative intensity than subject A. Even more noteworthy, subject B achieved a lower VO_2peak ($67.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) than Subject A ($75.9 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), but still out-performed subject A in the 3200 m run (9:36 [min:sec], versus 9:53 for Subject A). As previously mentioned, this was expected based on the individual lactate kinetics observed in subject B. These findings further suggest that, at least for these two individuals, VO_2peak was not as representative of performance as were BLA parameters. Similar relationships were observed for other subjects in this study.

The strong relationship between BLA parameters and performance, irrespective of VO_2peak values, have also been observed by a number of other investigators (Costill, 1986; Denis et al., 1982; Farrell et al., 1979; Martin, & Coe, 1991; Noakes et al., 1990)

Blood Lactate Parameters in Exercise Prescription

These examples further document that information obtained from individual BLA curves can provide essential and precise physiological information concerning the training state of an individual. As previously discussed, VO_2peak does not always delineate higher states of training, especially when performance is of primary concern. Essentially, these two BLA curves emphasize that exercise prescription (for competitive runners) based on VO_2 alone would not provide the same, or the optimal, training stimulus for different runners.

The degree of variability between subjects A and B provides strong support for the use of individual lactate kinetics for exercise prescription and training. For example, from the information provided on the BLA curves in Figures 3 and 4, each runner should ideally receive

prescriptions for different training paces. If the prescription is based on the percent of maximum concept alone, without considering LT pace/intensity, then the prescribed training pace for subject A (high VO_2peak , low LT) may be overestimated. The opposite would occur for subject B (see Figure 5) who possess a lower VO_2peak but a high LT. Therefore, exercise prescription based on the percent of maximum concept may not be appropriate for highly trained competitive runners. Other investigators have derived similar conclusions based on BLA studies of trained subjects (Katch et al., 1978; Weltman, Snead, Seip et al., 1990).

The American College of Sports Medicine (1990) has recommended that training intensity be carried out at 50% to 85% $\text{VO}_{2\text{max}}$ or from 60% to 90% of maximum HR. This range of intensities may not provide the optimal physiological stress for trained individuals. In support of this, the subjects in the present study achieved intensities of 84.5% VO_2peak and 90.7% HRpeak at the LT, which are close to 42 km (marathon) pace observed in highly trained runners (Costill, 1986) [see Table 2]. For highly trained runners, these training intensities are often above the intensity corresponding to LT. As shown in Table 2, VO_2 , VEL, and HR at $4.0 \text{ mmol}\cdot\text{l}^{-1}$ reached intensities of 93.9%, 90.4%, and 96.1%, respectively, which are typically associated with 5,000 m intensity for highly trained runners (Martin & Coe, 1991). Therefore, training intensities for competitive runners often include intensities between 80% to 97%. Training conducted below these intensities are generally used for recovery after competition and/or high intensity workouts, and for building and maintaining an aerobic base. Ultra-endurance athletes

also typically train at intensities below 80%.

Effect of Homogeneity

The low correlations were most likely the consequence of testing a homogeneous group of runners. The low SD of the physiological and performance data (see Table 2) provides support for this conclusion. Others have observed similar findings with testing homogeneous groups (Lehmann et al., 1983). However, the correlations in the present study, while considered low, were significant and deserve consideration.

The higher correlations observed between VEL and performance times had been observed by other investigators (Farrell et al., 1979; Noakes et al., 1990). In contrast, the correlation coefficients for the less homogeneous validation group in Weltman et al. (1987) were significantly higher.

Influence of Training State

In this study, the value for %VELpeak-LT was lower than for %VO₂peak-LT (see Table 3). Martin and Coe (1991) observed the VEL-LT to occur from 75% to 90% in trained runners, and typically 4% to 5% lower than %VO₂peak-LT. This was explained by the fact that highly trained runners are often able to achieve velocities that surpassed their VO₂peak velocity. Several of the subjects, who were typically middle distance specialists (800 m to 5000 m), possessed high anaerobic capacities, and were, therefore, capable of running at speeds beyond their aerobic capacity. In addition, the 1 minute break between stages for blood sampling may have provided adequate recovery for these runners to attain greater velocities.

Similar to the explanation given for %VELpeak-LT, the lower

percentages observed at FBLC may have been the result of higher peak values observed for the subjects in the present study (see Table 2).

Influence of Methodology

The findings in the present study may have been influenced by methodological differences in blood sampling, lactate analysis, and treadmill protocol when compared to similar studies reported in the literature. Studies have shown that BLA from venous blood samples are typically lower than BLA concentrations from capillarized blood from a finger tip or earlobe puncture (Foxdal et al., 1990; Robergs et al., 1990). Also, in the present study, total BLA (intracellular + extracellular) from a finger-tip puncture was measured, as opposed to only extracellular BLA from vena puncture by Weltman et al. (1987). Previously it was pointed out that measuring total BLA resulted in higher BLA concentrations. This has been well documented in the literature (Forrest et al., 1990; Van Handel et al., 1990). Therefore, FBLC of 2.0, 2.5, and 4.0 mmol·l⁻¹ using total BLA would be expected to occur at lower percentages of peak values than if only extracellular BLA were determined. The findings that VO₂ and VEL at 2.0, 2.5, and 4.0 mmol·l⁻¹ occurred at lower percentages of peak values was consistent with the methodology used in this study.

The use of a 1% treadmill inclination, to optimize the simulation of actual running, also may have contributed to increased BLA concentrations at lower intensities. Heck et al. (1985) pointed out that a 1% grade simulated the energy requirements of running on an artificially surfaced track. Others have also used a 1% grade for treadmill testing (Fohrenbach et al., 1987). In addition, increases of

13.4 m·min⁻¹ (0.5 mph⁻¹) per stage used in the present study were less sensitive than the 10.0 m·min⁻¹ increase per stage used by Weltman et al. (1987). As a result, the chance of error was increased.

The magnitude of this higher loading pattern can be illustrated comparing the pace per mile at two speeds that are 13.4 m·min⁻¹ apart. The velocity at 268.0 m·min⁻¹ (10.0 mph⁻¹) and 281 m·min⁻¹ (10.5 mph⁻¹) equates with 6:00 minutes and 6:18 minutes:seconds per mile, respectively. As a consequence of this rather large intensity interval, a subject may have been above or below $\dot{V}O_2$ at LT or FBLC. A smaller loading pattern would have decreased the magnitude of this error.

The subjects in the present study were expected to achieve $\dot{V}O_2$ and VEL at FBLC at higher percentages of peak values than the less-trained subjects in Weltman et al. (1987). As indicated in Table 3, this did not occur. Since Weltman et al. (1987) did not measure total BLa, higher intensities would have been achieved at lower lactate levels. This phenomenon occurred except for % $\dot{V}O_{2peak-LT}$ and %HR $_{peak-LT}$ (see Table 3), and this was most likely due to differences in LT identification. Weltman et al. (1987) identified LT as an abrupt nonlinear increase in BLa above resting baseline. The LT in the present study was identified as an abrupt nonlinear increase in BLa above a low exercise intensity baseline. This method of LT identification is strongly supported by others (Brooks, 1985; Martin & Coe, 1991).

Other investigators have observed greater percentages of $\dot{V}O_{2peak}$ at FBLC in highly trained runners compared to less trained runners (Costill, 1986; Noakes et al., 1990; Weltman, Snead, Seip, Schurrer et al., 1990). Therefore, it would appear that methodological differences

most likely contributed to these findings.

Excluding the stage loading pattern, this investigator believes that the methods used in the present study resulted in values more closely representing the true BLA response to incremental exercise. The use of a 1% treadmill grade and total BLA supports this assessment.

Summary

These findings suggest that the equations developed by Weltman et al (1987) to predict oxygen consumption at LT, FBLC of 2.0, 2.5, and 4.0 mmol·l⁻¹, and peak are valid when used with a younger and more highly trained subject group. In contrast, the findings do not support the validity of the equations to predict velocity at LT, FBLC of 2.0, 2.5, and 4.0 mmol·l⁻¹. Due to the small SEE and predictive error, the equation to predict VELpeak may be valid for exercise prescription with a group similar to the subjects in the present study in age and training level.

The predictive errors for each VEL variable were within the same range as the predictive errors observed by Weltman et al. (1987) who concluded that the errors were small enough to consider the equations valid for use in exercise prescription. However, this investigator believes that predictions for velocity in highly trained runners need to be more precise than what had been observed in this study and by Weltman et al. (1987).

To emphasize this point, an error of only 10 seconds per mile may cause a runner to train at 10 kilometer (10 km) race pace as opposed to a more appropriate training pace for a 10 km race, which is typically slightly above LT pace, or 10 seconds slower than 10 km pace. It is

obvious that overtraining in an individual may result from a seemingly insignificant 10 second per mile error. Conversely, undertraining may also result if training based on a 10 second prediction error for a given individual. A pace slower than the typical 10 km training pace described above would reduce the velocity to marathon training pace, or slightly below LT pace. This would not optimally stress the appropriate energy system, nor would this activate the muscle used for 10 km training.

In contrast, greater errors in predicting VO_2 values may not be as critical. This conclusion is supported by the findings that VO_2 is less related to performance and BLa parameters than is velocity (see Table 5, and Figures 3 and 4).

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The present study failed to support the validity of the equations to predict velocity ($\text{m}\cdot\text{min}^{-1}$) corresponding to LT, FBLC of 2.0, 2.5, and $4.0 \text{ mmol}\cdot\text{l}^{-1}$ presented by Weltman et al. (1987). However, due to the small SEE and predictive error, Weltman's equation to predict VELpeak may be appropriate for use in exercise prescription.

The findings of this study do support the validity of the equations to predict VO_2 ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) corresponding to LT, FBLC of 2.0, 2.5, and $4.0 \text{ mmol}\cdot\text{l}^{-1}$, and peak values developed by Weltman et al. (1987). However, due to the wide variability in BLA response to exercise, equations such as these should be used conservatively, keeping in mind the degree of error associated with each equation. In addition, these equations are most appropriate for individuals of similar age and fitness levels as those studied in the present investigation, and in Weltman et al. (1987).

Conclusions

The competitive endurance athlete is constantly searching for training techniques and practices which will enhance performance and provide the competitive edge. Unfortunately, very few have access to physiological testing facilities and trained personnel to assess their training needs. Thoroughly developed and cross-validated prediction

equations based on accepted laboratory techniques can provide easy access to valuable training information. Accurate prediction equations can be valuable training tools for both the athlete and coach when limited physical and financial resources do not allow for the desired tests and assessments.

Although a shroud of controversy still exists surrounding BLA and its relationship to exercise, there is sufficient evidence which supports its strong relationship to performance and state of training. Therefore, equations which accurately predict BLA parameters based on performance can provide information leading to appropriate training practices and optimal athletic performance.

The low, but statistically significant, correlations between performance and BLA parameters were most likely a by-product of testing a homogenous group, but did not seem to affect the accuracy, or inaccuracy, of the predictions. This conclusion is based on the similarity of prediction errors between the findings in the present study, and those observed by Weltman and colleagues (1987). However, the validity of the equations was highly dependent on the validity and accuracy of the laboratory testing procedures. Although there were differences in methodology between the two studies, this did not seem to influence the results.

It is apparent that procedures relating to the determination of LT and BLA still requires standardization among laboratories. The methods used in the present study were based on methodology which took into account both the simulation of actual running (i.e., track running) and individual lactate kinetics. As indicated in Chapter II, total BLA was

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believed to be more representative of BLA accumulation resulting from incremental exercise. The measurement of both intracellular and extracellular BLA took into account all potential variability which may result from unknown movement of BLA across the cell membrane.

The current methods were also more practical due to the storage capability of the blood samples in the Sodium Fluoride-Triton X-100 solution. Therefore, it is the belief of this investigator that prediction of BLA parameters should be based on the total BLA as opposed to unlysed samples of whole blood. In theory, the use of these methods should prevent the overestimation of training intensities for $\dot{V}O_2$ and $\dot{V}_{el}$ associated with LT, FBLO of 2.0, 2.5, 4.0 $\text{mmol}\cdot\text{l}^{-1}$, and peak values.

Practical Application

As with all predictive methods, the resulting values are based on imperfect relationships, and are specific to the subject group from which they were developed. Therefore, they can only provide rough estimates for specific groups of individuals. With this in mind, the equations to predict oxygen consumption ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) are most appropriate for males of similar age and training states as those observed in this study and by Weltman et al. (1987).

Due to the relative simplicity of test administration (i.e., 3200 m run), these equations may be used to provide valuable physiological data on each runner throughout an entire training season. For example, the field test can be administered and values calculated prior to the competitive season to aid in the development of individualized training plans. Periodic testing can also be accomplished during training and competitive seasons to evaluate the success of the current training

plan, or to plan for peak performances. Use of these equations in the postseason can provide a complete assessment of the entire training season.

The primary benefit of using these equations is the ease and simplicity of which they can be implemented. While not as precise as laboratory tests, they do not require expensive and sophisticated equipment, or specially trained personnel to complete the tests. Used appropriately, the values produced by the equations can provide the necessary training information for optimal performance.

Recommendations for Future Research

Research in the area of BLA and its relationship to exercise has been exhaustive. However, in pursuit of universally accepted concepts and the standardization of methods, research in this area needs to continue. Future studies might focus on the development of standardized methods and further examine the relationship between BLA and performance.

These and other related research areas might add to the existing literature in a number of ways:

- 1) Conduct a similar study which compares the BLA values obtained between field and laboratory settings.
 - 2) Validate the use of the Sodium Fluoride-Triton X-100 solution to treat and store blood samples.
 - 3) Cross-validate the equations in the present study derived from regression analysis between $\dot{V}O_2$, VEL, and the 3200 m time trial.
- Attempt to develop prediction equations with less error for a group of runners similar to those tested in this study.

- 4) Develop prediction equations for LT, FBLC of 2.0, 2.5, 4.0 mmol·l⁻¹ and peak values based on a submaximal steady-state field test.
- 5) Conduct a training study which compares exercise prescription based on the relative percent of maximum concept and exercise prescription based BLA parameters for untrained subjects.
- 6) Compare VO₂ and VEL values associated with BLA between runners specializing in different race distances. BLA parameters for other endurance athletes such as triathletes and dualists would also add to the existing data. Tests in both field and laboratory settings could be conducted in each mode of exercise to determine VO₂ and VEL associated with BLA.
- 7) Further examine the mechanisms of lactate production and uptake at the cellular level in trained endurance athletes. Compare different athletes (i.e., runners versus triathletes) and/or different training intensities and their effect on these processes.

Prediction equations similar to the ones tested in this study might be developed for swimming, cycling, and running which are based on a simple field test in each sport. The multisport specialist would then be equipped with performance-enhancing training tools based on BLA concentrations. The effects of transitions (i.e., swim to bike and bike to run) on BLA values, and subsequent effect on performance, could also be examined.

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APPENDIX A
INFORMED CONSENT

Informed Consent

Title: Validity of Equations to Predict Lactate Threshold and Fixed Blood Lactate Concentrations From a 3200 Run

I _____ of _____ years of age volunteer to be a subject in a study to determine the validity of equations to predict oxygen consumption and blood lactate concentrations based on a 3200 m run time. I understand that I will be required to complete a test for peak oxygen consumption and blood lactate analysis, and a 3200 m time trial.

Purpose of Tests and Benefits to the Endurance Athlete

The purpose of the treadmill test is to determine (by direct measurement) the amount of lactate that accumulates in the blood during progressive exercise. Pace per mile, heart rate, and oxygen consumed (the amount of oxygen taken in, transported, and used by the muscles for energy production), will be "matched" with certain concentrations of lactate. The runner will benefit by learning the heart rate and pace to train in order to optimally stress the aerobic and anaerobic energy systems. Interpretation of the results, including training suggestions based on the results, will be provided. Each subject will receive a copy of the test results.

The purpose of the 3200 m run is to determine if this field test can be used to accurately predict oxygen consumption and velocities (i.e., training paces) which correspond to certain lactate concentrations, such as lactate threshold ("Anaerobic Threshold"). Performance times will be entered into prediction equations then, compared to measurements obtained from the treadmill test. If the actual measurements obtained from the treadmill test and the predicted values are very similar, then the equations may be used with a high degree of confidence. Therefore, a field test such as a 3200 m run would provide a more feasible, and a rather "simple" method of determining optimal training intensities as opposed to invasive laboratory testing.

Informed Consent and Testing Instructions

In the days prior to the VO_2 peak/Lactate Threshold (LT) test, you will report to the Human Performance Lab in Mitchell Hall for a 15 minute orientation to the testing procedures, and to practice treadmill running.

On a separate day, no less than 48 hours following a high intensity run or exercise session (one day after a "recovery" day), I will complete the treadmill test for peak oxygen consumption (VO_2 peak) and blood lactate concentrations. The test will involve wearing a mouthpiece and headgear, which may cause drymouth during the test, and possibly jaw and gum soreness following the test.

Initial treadmill speed will be 8.0 mph⁻¹ (7:30 pace), and increased 0.5 mph⁻¹ after every 3 minute stage. I will run until volitional exhaustion. The test administrator will encourage you to continue running until you give an indication to end the test. The actual treadmill test may take from 20 to 40 minutes, depending on peak

levels reached. Additional time will be required for a resting blood sample for lactate, warm-up, stretching, and cool-down (approximately 5 Minutes each), for a total of 55 minutes.

A blood sample will be taken by finger-prick method at rest, and immediately following each 3 minute stage of the test. Between stages the subject will stop briefly (1 minute) for sampling, then resume running at the new speed. The tip of one of the three middle fingers on the left hand will be pricked for sampling. For each sample, alternating fingers will be used and the location of the prick changed to prevent excessive trauma. Depending on which stage is reached at peak oxygen consumption, 7 to 10 finger sticks may be required. To ensure subject safety, sterile methods and equipment will be used for each sample taken. Clean alcohol wipes and lancets will be used for each sample. A small bruise may develop as a result of the repeated finger pricks.

I will also be required to complete a 3200 m run (16 laps-2 miles) on the indoor track in Mitchell Hall on the U.W.-La Crosse campus. I am to complete the run as fast as possible. Split times will be provided every 400 m, including lap count and finishing time. This time trial will be done in groups of approximately 15 to encourage competitive running.

I understand that these tests involve strenuous exertion and thereby certify that I have no pre-existing conditions which may put me at risk, or prevent my participation in this study. For example: Heart disease, lung/respiratory conditions, high blood pressure, prone to fainting or seizures, and contagious diseases possibly transmitted through blood. I understand that the tests will be terminated if any abnormalities are observed. I also understand that I may terminate the tests at any time for any reason stated and/or unstated.

The tests will be conducted by Vern La Mere, a graduate student in the Human Performance program at the University of Wisconsin-La Crosse, and supervised by N.K. Butts, PhD., Professor of Physical Education. The tests will not be supervised by a medical doctor, and the person(s) giving the tests are not necessarily qualified to provide emergency medical support. Therefore, I understand that I must assume total responsibility for any adverse effects that may occur.

I have read and understand the procedures as described above and/or explained to me. I have been fully advised of the nature of the tests and possible risks involved, of which I assume voluntarily. I further agree to hold harmless the State of Wisconsin, the University of Wisconsin-La Crosse, including regents, employees, and the persons administering the tests.

In signing this consent, I certify that I am agreeing to the above statements freely and without reservation. I understand that I may withdraw my participation at any time.

Signed: _____

Date: _____

Witness: _____

APPENDIX B

PREPARATION OF SODIUM FLUORIDE/TRITON X-100
BUFFER SOLUTION

Sodium Fluoride-Triton X-100 Buffer Solution Preparation

Step 1. Mix the following substances in an appropriate sized flask and refrigerate until dispensed into individual 500 ul microcentrifuge tubes. Solution will last several weeks when capped and refrigerated.

1. 400 mg Sodium Fluoride (NaF) - Sigma (S-1504)
2. 25 ml Yellow Springs Instruments (YSI) buffer; Mix buffer solution as described in the YSI Model 23L
3. 3 drops Triton X-100 (Sigma-t-Octylphenoxypolyethoxyethanol).

Step 2. At any time prior to testing, dispense 50 uls of NaF-TX100 solution into 0.5 conical auto-analyzer tubes. Cap and refrigerate until needed.

Step 3. When the sample is obtained, use the YSI Model 23L pipet to expel 25 uls of whole blood into a tube containing the NaF-TX100 solution. Mix gently for several seconds by agitating the tube. Then assay with the YSI lactate analyzer and multiply the displayed value by three.