



RESEARCH ARTICLE

Identification and Validation of the Lactate Threshold Velocity using the Y-Intercept and Slope of the Fit Curve (YIS Method)

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Abstract

Purpose: To present a new method for determining the individual Lactate Threshold velocity (LTv) in trained swimmers using the intercept and slope (YIS) of the Lactate-Velocity curve (La-V).

Methods: Forty-two national-level swimmers undertook a 7 × 200 m discontinuous incremental swimming step test. The LTv was determined by a mathematical formula that calculated the Lactate Threshold (LTv) as a function of the y-intercept and slope of the Lactate-Velocity curve (YIS method, where $LTv = -0.217 \times [y\text{-intercept (La-V)/slope (La-V)]$) and compared to an existing Fixed Slope (FSM) Method, which had been seen to be the most consistent of 4 methods and used a similar slope protocol. Subsequently, on three occasions over a six-week period, using twelve different swimmers, the method of determining LTv was compared to three practical methods of validating the LTv: a 2000 m time trial, 24 × 100 m, and 10 × 300 m swim sets.

Results: The slope of the La-V curve for Freestyle was significantly different between YIS and FSM ($p = 0.03$). The mean lactate at LT with the YIS method (3.2 ± 0.4 mM) was significantly lower than FSM (3.4 ± 0.3 mM). Swim velocity at LT was not significantly different between YIS and the FSM, $p = 0.40$.

Conclusions: The YIS method for determining the LT and LTv, derived from the 7 × 200 m incremental step test, provides an objective means of quantifying the lactate threshold in swimmers.

Keywords

Swimming, Blood lactate, Anaerobic threshold, Step test, Lactate-velocity curve, Slope

Introduction

Although the Lactate Threshold (LT) has lost some of its status as a marker of exercise intensity, the LT does mark a metabolic transition that, when we are looking to explain energy timelines, can provide an important perspective. This paper is the first of a series looking to clarify and transform how we monitor intensity of exercise. As such we need to create a more robust method of identifying LT.

The LT has been typically defined as the highest constant workload that can be sustained without incurring progressive increases in blood lactate concentration [1-3]. A number of methods have been used to detect the exact exercise intensity at which it occurs. Initial attempts with visual detection were open to considerable experimental error [4]. Lactic acid concentration in the blood may follow an exponential rise rather than a 'threshold break' in its dynamics, which further underlines the necessity of a valid, reliable and accurate means of identifying the LT. The lactate profile is further influenced by the specific sport and event in which the athlete trains and the length of time spent on specific training tasks [5].

A number of graded and progressive exercise test protocols have evolved for the determination of the Lactate Threshold velocity (LTv). Initially a standard reference point such as the 4 mM was used to identify the velocity at submaximal workloads [2,6,7]. This appears

to be appropriate for athletes in endurance-based activities where the repeats used are longer than 4 minutes (or where a steady state may be reached). In many sports, such as in swimming, the events last less than 8 minutes (typically 45 secs to 3 minutes). Adopting a fixed 4 mM may lead to over-estimation of workloads in training as it has been found that the workload and duration of the graded exercise tests influences the determination of LT_v [8-11]. Careful selection of protocol is therefore important if meaningful results are to be obtained, with alterations of work-load level and duration changing the corresponding threshold value in graded exercise tests [3]. This demonstrates that the level of lactate in the blood is dependent upon work-load intensity and duration [3]. Discontinuous graded exercise tests allow some lactate elimination, leading to a shift of the lactate curve toward the higher speeds for a set intensity [12].

A number of investigators have proposed methods to estimate both LT and LT_v by mathematical techniques [13-15]. The blood lactate concentration of the calculated LT between the different mathematical models can differ by 2 mM from the same data [6]. Borch, et al. [1] suggested the use of an exponential function $La = a * e^{dx} + c$ and identified the point on this curve that related to a fixed slope of 0.086 [1]. It was reported in this paper that this point was related favorably to a lactate level of 3.0 mM. The possibility of over-estimating LT_v is increased with a fixed slope method as it ignores individual variation elicited by genetic pre-determinants, training background, and specificity of sporting activities.

There is no universally accepted method that calculates a valid estimate of LT as a function of the lactate-velocity profile using a discontinuous, incremental test (such as the 7 × 200 m swimming step test) using shorter repeat periods (2-3 minutes). The aim of this study was to describe a specific method for calculating the point of LT. The proposed Y-Intercept Slope (YIS) method was compared with the Fixed Slope (FSM) Method. Other methods (D-Max and Fixed Tangent) had already been found to be less reliable. The ability of the YIS method to assess changes longitudinally over a six-week period in the same stroke (freestyle) was also investigated.

Methods

Subjects

Forty-two international standard swimmers from the Australian Institute of Sport and New Zealand national squad. All subjects were male and aged between 17 and 24 years. Freestyle was the stroke used for all tests. All subjects provided written informed consent for the physiological testing procedures, which had prior approval from the Ethics Committee of the Australian Institute of Sport.

Study design

The subjects performed a graded sub-maximal swimming test of 7 × 200-meter freestyle swims as a basis for the assessment of aerobic fitness. This testing was conducted in accordance with the protocols of the Australian National Swimming Team [16]. For all subjects, training consisted of a mixture of low, moderate and maximal intensity aerobic work, short sprints and pool-based stroke specific drills and exercises. Weekly swimming training volume averaged 54 ± 19 km.week⁻¹ (mean ± SD) over the six weeks. All swimmers also carried out land-based training between three and five times per week consisting of resistance training circuits, strength training and flexibility work.

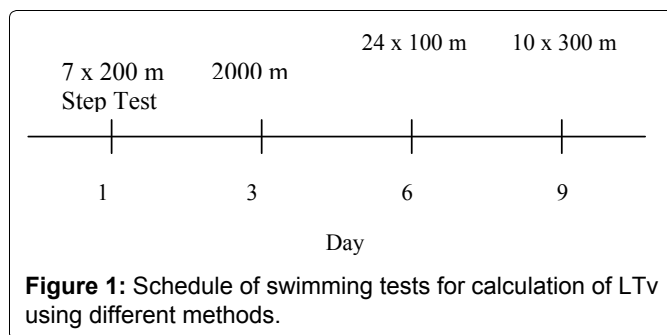
Lactate profiling

7 × 200 m step test was conducted on a 5:30 min cycle. Dietary intake, 24-hour prior training load, and pre-test warm-up were all standardized for each test. The seven swims were performed at an even pace, controlled by the swimmer. Each swimmer was provided with individual target times based upon the personal best performance on freestyle over 200 m. The range of target times was approximately 30 seconds and progressed from slowest to fastest in consistent increments [16,17]. This progression equates to an approximate rise in intensity from 70% of maximal (first swim) to 100% of maximal effort (seventh swim).

Each 200 m swim began with a push start while partially submerged in the water. Mean swimming velocity over the 200 m was recorded for each effort as well as the 100 m split times using a manual stopwatch. Stroke count was recorded for each 50-meter lap to allow the calculation of the stroke characteristics (distance per stroke and the stroke rate). Heart rate was monitored immediately on completion of each swim with a Polar heart rate monitor (Polar Electro OY, Kempele, Finland). Capillary blood (25 µl) was collected from finger-tip or ear lobe puncture one minute after the completion of each swim. Lactate concentration was analyzed by a Lactate Pro Lactate meter (Axon Labs., Austria). All tests were completed at the same time of day on the three different occasions for each swimmer.

Validation study

As a means of validating the method, an additional twelve swimmers from the South Australian Swimming Distance Squad were required to undergo the 7 × 200 m swimming step test plus three additional tests in the pool over a 9-day period (see Figure 1). On day 0 all subjects undertook the 7 × 200 swimming step test described above. On day 3 all subjects undertook simultaneously an interval set of 10 × 300 m. On day 6 the subjects undertook a second standardized interval set of 24 × 100 m intervals. Finally, on day 9 the swimmers completed a continuous maximal effort 2000 m time trial (2000TT). This schedule of testing was designed to



validate the YIS methods in three separate ways: i) Comparison with the existing FSM mathematical technique; ii) Comparison with two standard interval training sessions; iii) Comparison with a continuous 2000TT.

Validating the YIS method

Determination of YIS and FSM Lactate Thresholds - The first means of validating the YIS method compared the calculated LTV value with that obtained with the previously described FSM method. The Y-Intercept Slope method (YIS) calculates the LTV from the slope and y-intercept of the blood lactate - velocity curve, as distinct from the point of onset of blood lactate accumulation. This method is based upon determining the y-intercept (blood lactate concentration), which is the regression line through the data points (x's and y's in this case for swimming velocity and lactate concentration), returning the point (lactate concentration at LT) where the regression line intersects the y-axis of the paired data. The LTV (x-value) is calculated from the LT (mM) (y-value) by inserting this value into the regression equation (see Figure 1). Initial pilot work showed that YIS analysis using the abbreviated upper portion of the lactate-velocity curve from the 4th to the 7th data points (as opposed to the full lactate curve using all 7 data points) generated a value that correlated more closely with other estimates of the LTV. The modified FSM method involves calculating the point that yields the maximal perpendicular distance from the lactate curve to a tangent line formed from the aerobic threshold (at the velocity corresponding with 0.4 mM rise in lactate concentration over the baseline) to the peak lactate value [18].

Interval Training Sessions - The second means of validating the calculated LTV using the YIS method was a comparison against the mean velocity achieved in two standard swimming interval training sessions. The first session consisted of 24 × 100 m intervals on a 1:30 (min:sec) cycle. The second session consisted of 10 × 300 m intervals on 4:30 (min:sec) cycle. The swimmers were asked to swim each interval at an effort corresponding to a heart rate of approximately 160 ± 5 beats per min. These sessions are typical of those used in competitive swimming as anaerobic or lactate threshold training sessions. Heart rate and lactate was measured at the completion of each 100 or 300 m effort using the same protocols as stated above except lactate was only taken at the completion of each set. The time for each effort

was recorded manually with a Seiko S101A stop watch (Seiko Corporation, Japan).

2000 m Time Trial - A third means of validating the YIS method was a comparison against the mean velocity achieved in a continuous maximal effort 2000 m time trial. For this test the athletes were instructed to swim the required 2000 m as fast and as evenly as possible. Total time for the 2000 m and 100 m split times were recorded using a Seiko S101A stop watch (Seiko Corporation, Japan). The 1st and last 100 m split were dropped for the calculation of average 100 m time throughout the swim. All athletes performed the freestyle stroke. Heart rate and blood lactate concentration was measured within 60 secs of completion of the time trial with as with the previously stated protocols.

Calculation of YIS for determining LT

The Y-Intercept Slope method (YIS) calculates the LT as distinct from the point of Onset of Blood Lactate Accumulation (OBLA). The YIS method is based upon determining the intercept which is the regression line through the data points (x's and y's in this case of swimming velocity and lactate concentration), returning the point where the regression line intersects the y axis of paired data where:

The intercept =

$$(1) a = y - bx$$

and the slope b =

$$(2) nxy - (\sum x)(\sum y)$$

$$n\sum x^2 - (\sum x)^2$$

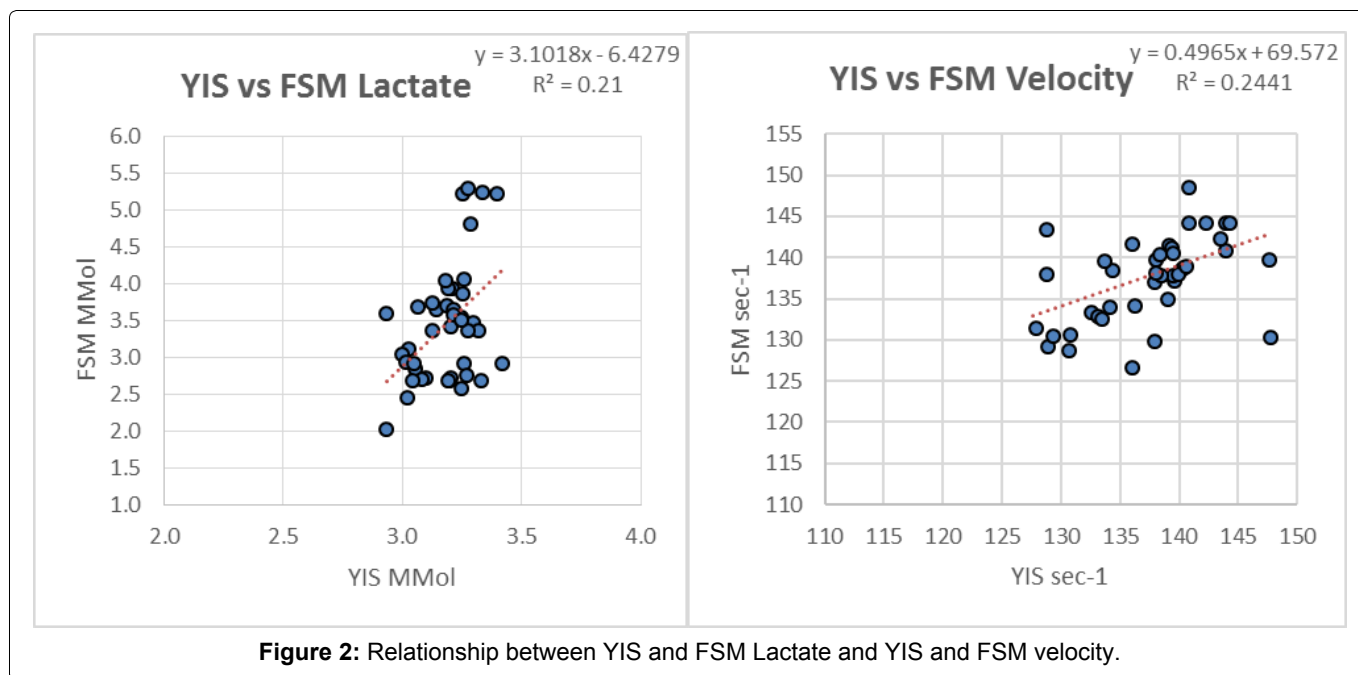
The slope is the vertical distance divided by the horizontal distance between two points of the profile. This value indicates the rate of change between points on this profile. By dividing the intercept by the slope of the profile and multiplying it by a constant the lactate value at the LT is estimated.

$$LT = (3) -0.0217 \times y - bx$$

The methods of Borch, et al. [1] has been proposed as a means for identifying the LT. For comparison purposes, it was necessary to adopt a single criterion for identifying the difference between the calculated lactate values of the four methods. An example of this standardization was to determine the slope of each profile by the methods of Borch [1] and convert this to a tangent angle. This approach permitted a comparison of these two existing methods to the proposed YIS method for determining LT. The D-max method involves constructing a tangent from the lactate threshold to the peak lactate value [17].

Statistical analysis

The results are expressed as mean and standard deviation ($X \pm SD$). Each profile of lactate and velocity (the La-V profile) was plotted and assessed for goodness of fit (Pearson's Product Moment correlation) with a 3rd or-

**Table 1:** Mean profile data and for freestyle (n = 42).

Mean	SD	Hi	low
Time (Secs)			
146.3	5.8	157.4	133.8
141.8	5.3	152.6	128.3
137.4	4.7	148.0	126.2
132.9	4.8	144.9	123.0
128.8	4.3	141.8	122.4
126.0	4.3	138.4	118.5
123.6	4.8	135.1	114.8
Lactate (Mmol)			
Mean	SD	Hi	low
1.3	0.5	2.9	0.7
1.6	0.6	2.8	0.6
1.9	0.7	3.1	0.8
2.6	1.0	4.4	0.8
3.7	1.4	6.8	1.3
5.6	2.1	9.3	2.0
7.9	2.5	12.6	2.2
11.4	2.5	16.2	6.3
Heart Rate (BPM)			
Mean	SD	Hi	low
136	15	160	90
143	11	165	120
152	11	170	130
161	9	177	140
169	9	186	147
176	9	198	150
183	11	210	160

der polynomial plot. Student's t-test was carried out to determine statistical differences. Statistical analysis was completed with SPSS v19. Results were considered as significant when $P \leq 0.05$.

Results

7 × 200 m Step Test Results

The results for the 7 × 200 m step test are presented in Table 1. From the slowest to fastest efforts, freestyle

times for the 200 m ranged from 146.3 ± 5.8 to 123.6 ± 4.8 sec. These times are indicative of the highly-trained nature of the subject group. Blood lactate values ranged from 1.3 ± 0.5 to 11.4 ± 2.5 mM. The calculated LT 200 m times by the YIS method was: 137.2 ± 5.1 sec (86% of max swim pace).

Comparison of predicted lactate concentration (mM) at LT

The predicted lactate for swimming freestyle at the LT point, by use of the YIS method was 3.2 ± 0.1 mM. This was lower than the turn point estimated by using the FSM method (mean 3.4 ± 1.0 mM, $p = 0.01$). The Rsq value is shown in Figure 2. This figure demonstrates that although the LT detected by the different protocols appeared to be close, the relationship between them is poor (RSQ 0.2). There was a 91% likelihood of a mechanistic difference between the two methods. The change in mean was 0.3 mM with confidence limits of 0.2 and 0.5 Table 2.

Comparison of predicted AT pace

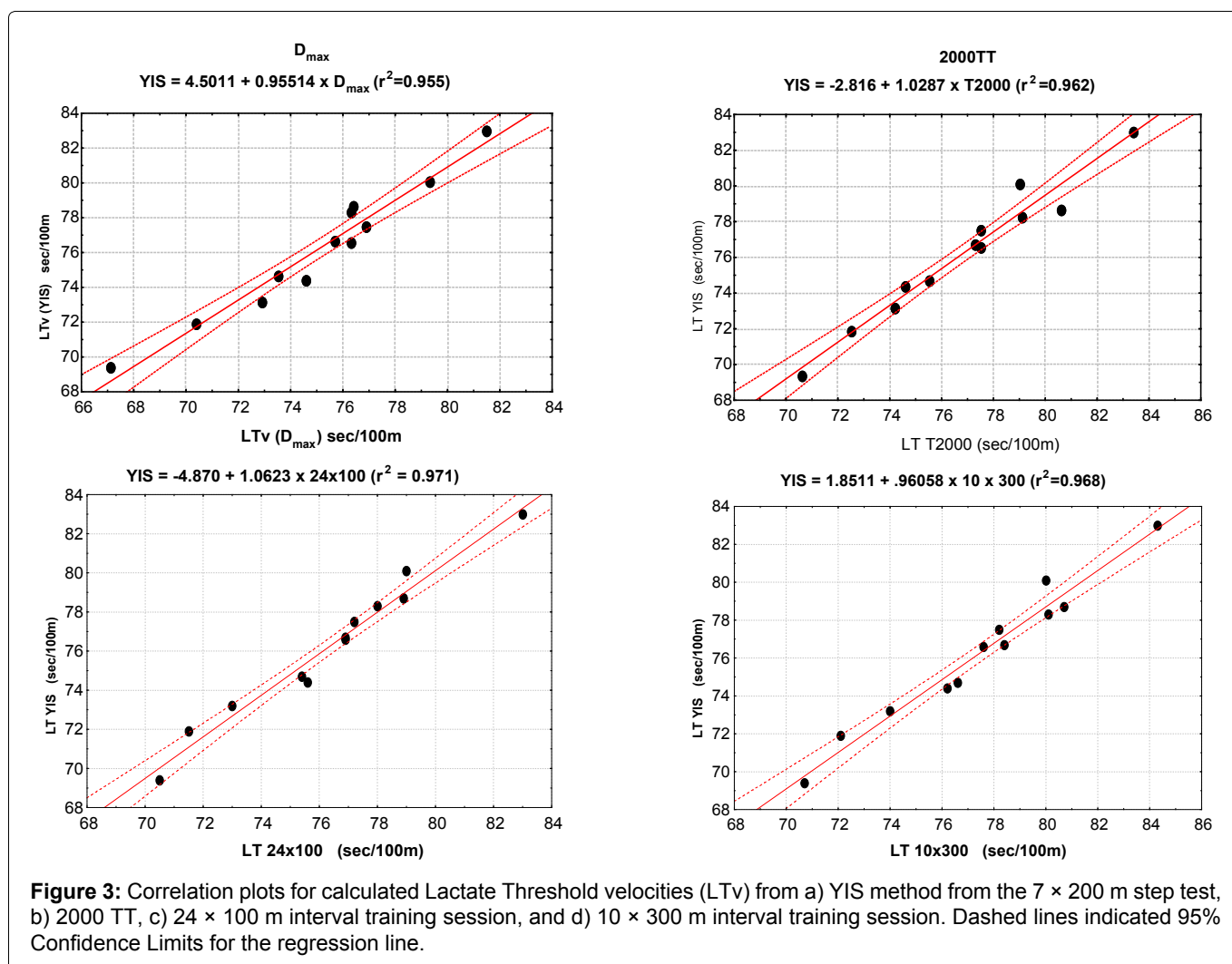
The calculated swim pace at LT (seconds per 200 m) determined by the two different methods was not significantly different between the predicting 200 m LT times of YIS (137.2 ± 5.1 sec), and the FSM method (136.4 ± 4.9 sec; $p = 0.3$). The Rsq is shown in Figure 2. Again, although the means appear to be similar, the reality is that there is little agreement in the speed determined by the two methods in paired samples.

Results of validation study

The comparison data for the 5 methods of evaluation of LT and LTv are shown in Figure 2. The calculated LTv, mean heart rate, and mean blood lactate concentration using the YIS methods and the mean velocities obtained from the FSM, 2000TT, 24 × 100 m and 10 ×

Table 2: Comparison of the Lactate Threshold velocity (LTv), heart rate and blood lactate concentration at the LTv, for the YIS method compared with the D_{max} method, the 2000 TT, and the 24 × 100 m and 10 × 300 m training sets.

Method		YIS	FSM	2000 TT	24 × 100 m	10 × 300 m
Lactate Threshold Velocity (sec/100 m)	Mean	76.2	75.1	76.8	76.3	77.4
	Std. Dev.	3.7	3.8	3.5	3.5	3.8
	95% CL	73.8-78.6	72.4-77.5	74.6-79.1	74.1-78.5	75.0-79.8
	Post Hoc p-value	-	p = 0.00	p = 0.22	p = 0.99	p = 0.00
Heart Rate (bpm)	Mean	167	164	178	168	174
	Std. Dev.	9	10	8	9	7
	95% CL	161-172	158-170	172-183	162-173	170-178
	Post Hoc p-value	-	p = 0.74	p = 0.00	p = 0.98	p = 0.01
Lactate (mM)	Mean	3.2	3.4	3.1	2.8	3.5
	Std. Dev.	0.12	0.8	0.6	0.5	0.6
	95% C.I.	3.1-3.3	2.6-4.1	2.7-3.4	2.5-3.2	3.1-3.9
	Post Hoc p-value	-	p = 0.89	p = 0.42	p = 0.99	p = 0.01



300 m training sets are shown in Table 2. The Mean LTv derived with the YIS method (76.2 ± 3.7 sec/100 m) was similar to both the 2000TT (76.8 ± 3.6 ; $p = 0.22$) and the 24 × 100 m set (76.3 ± 3.5 ; $p = 0.99$), but significantly slower than the FSM method (75.1 ± 3.7 ; $p = 0.00$) and faster than the 10 × 300 m set (77.4 ± 3.8 ; $p = 0.00$) as shown in Table 2.

The mean blood lactate concentration at the LT with the YIS method (2.7 ± 0.4 mM) was similar to that of the 2000TT (3.1 ± 0.6 ; $p = 0.42$) and the 24 × 100 m set (2.8 ± 0.5 ; $p = 0.99$), but significantly lower than the 10 × 300

m set: 3.5 ± 0.6 ; $p = 0.11$). No differences were observed for heart rate, at LTv for YIS (167 ± 9 bpm) and the 24 × 100 m set (168 ± 9 bpm; $p = 0.98$), but YIS heart rate was significantly lower than the 2000TT (178 ± 8 bpm; $p = 0.00$) and the 10 × 300 m set (174 ± 7 ; $p = 0.01$).

Correlation plots for calculated LTv using the YIS method compared with the FSM method, and the mean swimming velocities obtained from the 2000TT, 24 × 100 m, and 10 × 300 m training sets are shown in Figure 3. All four comparisons show a high correlation $r > 0.95$. The slope of the regression plots indicates the degree of agree-

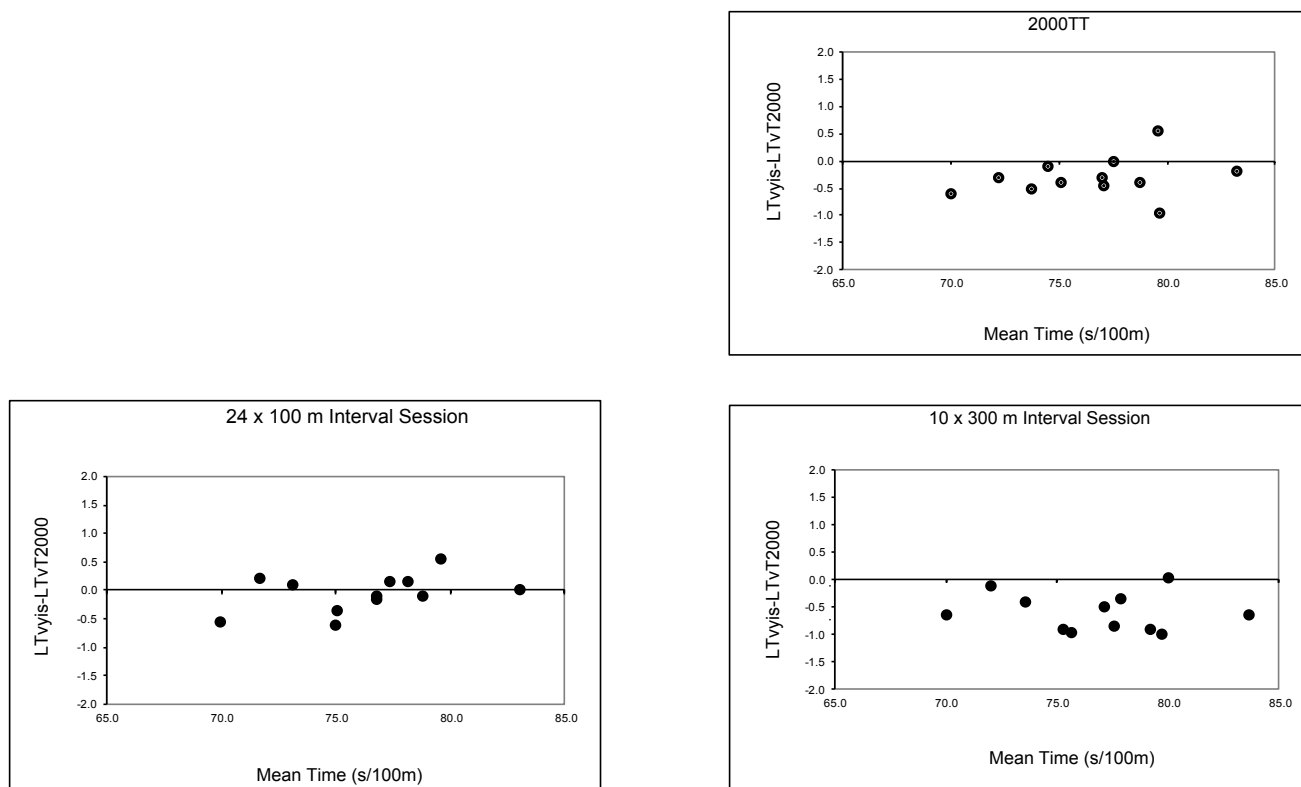


Figure 4: Bland-Altman level of agreement plots showing the relationship between LTV derived with the YIS method compared with: a) 2000 TT, b) 24 × 100 m interval session, and c) 10 × 300 training session.

ment between the LTV detection methods and standard swimming training sets. The values in comparison with the YIS method were a factor of 0.96, 1.03, 1.06, and 0.96 for the FSM, 2000TT, 24 × 100 m and 10 × 300 m sets respectively.

The level of agreement results are shown in Figure 4. These results indicate that the LTV values calculated with the YIS method are in good agreement with the mean velocities obtained from the criterion 2000TT test, 24 × 100 m, and 10 × 300 m sets. This is particularly evident when comparing the YIS method with the 2000TT and the 24 × 100 m set, where all the values were within 0.5 sec of the combined mean LTV. The FSM values were consistently faster (up to 1.0 sec) and the 10 × 300 m values consistently slower (again up to 1.0 sec) than the YIS method (see Table 2).

Discussion

The present study has outlined a method of assessing the LTV in highly trained swimmers. The YIS method calculates the lactate threshold as a function of the blood lactate - velocity curve, using the slope and the intercept. Where this is different to previous methods is that the slope is individual rather than fixed. Adding the intercept also allows a further individualization of the assessment that is not available from a single best-fit arrangement. Although the profiles of swimmers who took part in this study showed an exponential relationship between velocity and blood lactate, there were individual differences in slope angles that would have been missed using previous methods. The findings of

studies using both an escalation test [1] and a discontinuous ramp test examining the relationship between exercise intensity and blood lactate concentration [13] can be more closely and accurately determined by using the YIS method. These data also demonstrate the validity of the YIS method to predict an appropriate pace for swimmers in shorter repetition distances.

A number of researchers have suggested that a blood concentration of 4 mM can be used as the criterion value for identifying the LT [2,3,6]. Most of the studies on the determination of the LT and LTV have been conducted with running or cycling. These are generally longer activities that involve different muscle recruitment patterns that could affect LTV value [3,19]. Endurance-trained athletes may have a lower individual lactate concentration at LT than other athletes [1]. The mean lactate concentration at the LT for freestyle found by the YIS method (3.2 mM) was higher than that suggested in previous papers (3.0 mM) [20] as a set value that could be assumed by using an FSM method and was significantly lower than that found by the FSM method (3.4 mM) in this study.

The LTV is suggested to be representative of the point where purely aerobic work becomes partially anaerobic [11,21]. The amount of anaerobic work being performed at this point is not readily identifiable with routine lactate testing. The potential for overestimating the anaerobic contribution when using shorter duration intervals in a ramp test is greater than with a continuous ramp method, where there is less potential for working

higher than the LTV speed. This assertion is supported by observations that discontinuous methods can over-estimate work intensities at the LTV [6].

Results obtained from discontinuous methods must be carefully interpreted to ensure that the correct intensity is achieved. The YIS method offers the ability to identify the specific LTV for each individual swimmer. Rather than if the LT occurs at a specific lactate concentration above the designated aerobic threshold (i.e. aerobic threshold (mM) + 1.0 mM, or at a set lactate of 3 mM) [20], or a fixed lactate concentration (e.g. 4 mM) [21]. Individualization of testing elite athletes is a legitimate conceptual approach and the YIS method allows the individual LTV to be calculated for each profile.

Where pace was considered, no significant difference was found between the estimation of swim speed, as determined by the two methods. Although the difference between the two methods was not significantly different, in practical training terms, a 1 second difference in repeat times can make the difference between successfully completing a training set at a set pace over 2000-3000 m and seeing the swimmer unable to maintain pace, stroke characteristics, and therefore performance outcome. There were at least 10 subjects where the variation in pace determined by the YIS method and FSM method was over 3 seconds and up to 8 seconds in disagreement. This would cause a likelihood of training failure if these pace times were to be set at this level. Over the six-week study period, this model elicited a high correlation ($r = 0.98$) between the identification of the relative "Y" axis occurrence of the LTV while still showing left/right changes in the lactate profile against speed. The high correlation between YIS and the practical assessments demonstrated the stability and predictive nature of the YIS method. Most of the training classification systems used in competitive sports are based on the accurate determination of the LTV. Although the YIS model used the 7 × 200 m step test, it appears to be robust and transferable to a range of monitoring scenarios.

In conclusion, the YIS method for determining the LTV of swimmers is based on the y-intercept and slope of the lactate profile and is sufficiently sensitive to identify training-induced changes over a period of six-weeks. The formula $LTV = -0.217 \times [y\text{-intercept (La-V)}] / (\text{slope (La-V)})$ provides an objective method for evaluating the lactate-velocity curves in trained swimmers. Test re-test relationships are strong and represent a high level of reproducibility. The validation methods support that the newly proposed YIS method is an accurate and valid means of determining the LT and LTV in highly-trained swimmers. This method is more likely to produce an effective estimation of the correct workload for the intensity based upon the LTV in short duration repetitions. In this respect, when testing elite swimmers, the YIS method represents a step forward from the existing methods,

of which the FSM [6] model appeared to be the best. Caution is suggested in applying the model to different groups until further studies have been carried out.

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