

## ABSOLUTE LACTATE THRESHOLD PREDICTS ENDURANCE PERFORMANCE IN MASTER ATHLETES

A.E. Rossuello<sup>1</sup>, S.A. Hawkins<sup>1,2</sup>, R.A. Wiswell<sup>1</sup>

<sup>1</sup>University of Southern California, Division of Biokinesiology and Physical Therapy, USA; <sup>2</sup>California Lutheran University, Department of Exercise Science and Sports Medicine, USA

**Abstract.** In master athletes the relationship between lactate threshold (LT) and endurance performance is unclear, possibly due to age-related decrease in  $\text{VO}_2\text{peak}$ . To determine whether an absolute measure of LT was a significant predictor of 10km running performance in master athletes, 51 men master athletes (40-77 yrs) performed a treadmill graded exercise test with minute-by-minute venous blood samples for lactate analysis. Training status and recent 10 km performances were determined by questionnaire.  $\text{VO}_2\text{peak}$  ( $r=-0.56$ ,  $P<0.001$ ) and the two absolute measures of LT, Power at LT ( $r=-0.44$ ,  $P<0.001$ ) and  $\text{VO}_2$  at LT ( $r=-0.39$ ,  $P=0.002$ ), were significantly correlated to 10 km performance, but relative LT (% of  $\text{VO}_2\text{peak}$ ) was not ( $r=0.10$ ,  $P=0.48$ ).  $\text{VO}_2\text{peak}$  ( $R^2=0.31$ ,  $P<0.001$ ) and Power at LT ( $\Delta R^2=0.08$ ,  $P=0.015$ ) were significant predictors of 10 km performance. These findings suggest that absolute LT is predictive of endurance performance in master athletes. Furthermore, relative LT is not a useful evaluation of LT in master athletes, possibly because of the age-related decrease in  $\text{VO}_2\text{peak}$ .  
(*Biol.Sport 26:105-112, 2009*)

*Key words:* exercise, distance, aging, running, performance

### Introduction

Peak oxygen consumption ( $\text{VO}_2\text{peak}$ ) and lactate threshold (LT) have been reported to account for most of the observed variance in endurance running performance [3]. Relative LT ( $\text{LT}_{\text{rel}}$ ), which is the percentage of  $\text{VO}_2\text{peak}$  at which LT occurs, has repeatedly been shown to be the best predictor of endurance running performance (3 km – Marathon) in young distance runners [6-8]. In contrast, studies of master athletes have demonstrated differing results. Work from this lab [11,14] found that only  $\text{VO}_2\text{peak}$ , not  $\text{LT}_{\text{rel}}$ , predicted endurance

---

Reprint request to: Amerigo Eric Rossuello, USC Division of Biokinesiology and Physical Therapy, 1540 East Alcazar St., CHP-155, Los Angeles, CA 90089, USA  
Tel.: 323-442-2180; Fax: 323-442-1515; E-mail: amerigor@usc.edu



performance. From these results we concluded that LT may not be predictive of performance in older adults.

However, we have continued to search for explanations to this paradox, given the significance of LT to endurance performance. In a follow up study, we noted that a longitudinal increase in LT in these older athletes was due to a concurrent decrease in maximal aerobic capacity [11,14]. Therefore, an increase in  $LT_{rel}$  measured in master athletes may be an indication of increased aerobic conditioning or a decrease in aerobic capacity, providing a possible explanation for the previous work suggesting no correlation between LT and endurance performance.

In this study, we assessed lactate threshold using two absolute measures of LT ( $LT_{abs}$ ) to minimize the affects of decreased  $VO_{2peak}$  on LT assessment. Because the relationship between  $LT_{abs}$  and performance in young athletes has been described as very robust [2,4-6], we hypothesize that absolute LT will predict endurance performance in master athletes. The purpose of this study was to determine whether absolute lactate threshold measurements are significant predictors of endurance performance among male master athletes.

## Materials and Methods

*Subjects:* Fifty-one male master athletes were selected from a longitudinal, descriptive study at the University of Southern California, Los Angeles, CA. Subjects were considered master athletes if they were 40 years or older, had trained for at least 5 years, were currently training at least  $32 \text{ km}\cdot\text{wk}^{-1}$ , and competed at least once per year in organized running competitions. The study was approved by the Institutional Review Board (IRB) of the University of Southern California. All subjects gave written informed consent according to guidelines established by the IRB of the University of Southern California.

*Anthropometric measures:* Upon arrival in the laboratory, height was measured with a stadiometer and body mass was determined on a calibrated Homs beam-scale. Residual lung volume was assessed using the oxygen dilution technique [13], after which body composition was determined by hydrodensitometry. Body density was calculated and percentage of body fat determined from body density using the equation of Siri [12].

*Maximal aerobic capacity:*  $VO_{2peak}$  was determined using a continuous, incremental protocol on a motorized treadmill. The initial speed and grade were 2.5 mph and 0%, respectively, with increases of 0.5 mph and 2% every 2 minutes until subjective exhaustion. The volume of expired air, volume of oxygen consumption, and volume of carbon dioxide production were determined by a Parvomedics



metabolic system (Consentius Technologies, UT).  $\text{VO}_2\text{peak}$  was said to be achieved if the test met two of the following criteria: 1) RER greater than 1.05, 2) heart rate within 10 bpm of age-predicted maximum, 3) plateau in  $\text{VO}_2$  with increasing workloads, and 4) blood lactate concentrations greater than  $7\text{mM}\cdot\text{L}^{-1}$  (post-hoc). Unless specified otherwise, all mentions of  $\text{VO}_2\text{peak}$  refer to relative  $\text{VO}_2\text{peak}$ . EKG was monitored continuously throughout exercise. Heart rates were recorded at rest, at the end of each minute during exercise, at  $\text{VO}_2\text{peak}$  (maximal heart rate, MHR), and for the first 5 minutes post exercise.

*Blood sampling:* Blood was drawn from an in-dwelling catheter into pre-chilled EDTA Vacutainer tubes at the end of each minute of exercise. Blood samples were also taken at 2 and 5 minutes post exercise. Samples were immediately centrifuged, pipetted into storage vials, and stored at  $-80^\circ\text{C}$  until analysis. Samples were analyzed for lactate concentrations using a Yellow Springs Instrument 23-L Lactate Analyzer (Yellow Springs, OH, USA). Calibration and linearity checks were run before and throughout the analyses.

*LT determination:* Minute values for blood lactate concentration were plotted against time, and the graphs were visually inspected for the time point at which a noticeable change in slope occurred, which was identified as the LT. Five testers individually analyzed each graph. The coefficient of variation for the individual determinations of LT was 1.2% between the five testers, as determined from a sample of 100 graphs chosen randomly from the entire longitudinal study. Two methods were used to determine absolute LT. 1) The time point at which LT was achieved was matched with the values of  $\text{VO}_2$ , and expressed as  $\text{VO}_2$  at LT ( $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ). 2) The speed and elevation of the treadmill at the time point when LT was achieved was used to determine the power output associated with LT relative to body mass ( $\text{N}\cdot\text{Rate of Vertical Displacement}\cdot\text{kg}^{-1}$ ,  $\text{W}\cdot\text{kg}^{-1}$ ). Relative LT ( $\text{LT}_{\text{rel}}$ ) as a percentage of  $\text{VO}_2\text{peak}$  was determined by dividing the oxygen consumption at LT by the maximal oxygen consumption.

*Training and performance:* Athletes self reported training and performance data via questionnaire. Parameters included years of training, distance run per week ( $\text{km}\cdot\text{wk}^{-1}$ ), training frequency ( $\text{d}\cdot\text{wk}^{-1}$ ), and best performance for a 10 km performance for a competitive race within the preceding 4 months [11,14]. Athlete responses were confirmed by oral interview on the day of testing. All athletes confirmed having no breaks in training during the time between their best performance and testing in our laboratory.

*Statistical analyses:* Data were entered into spreadsheets and analyzed using the Statistical Package for the Social Sciences (SPSS) v. 14.0. Pearson correlation



coefficients were used to describe the correlations between metabolic variables and performance. Partial order correlations were used to determine the influence of confounding variables such as age. Multiple regression analysis (stepwise) identified significant contributors to the variance in each 10 km performance. Statistical significance was pre-determined at  $P < 0.05$ .

## Results

Subject characteristics are summarized in Table 1. Subject age ranged from 40 to 77 yr ( $53.6 \pm 8.4$  yr). During the metabolic testing, the mean ( $\pm$ SD) MHR was 173 ( $\pm 12$ ) bpm and mean maximum RER was 1.16 ( $\pm 0.14$ ), which indicated that subjects were able to attain maximum effort during the  $\text{VO}_2$ peak testing. The self-reported frequency ( $\sim 6$  d $\cdot$ wk $^{-1}$ ) and volume ( $\sim 64$  km $\cdot$ wk $^{-1}$ ) of training status, and the results for body fat ( $17.3 \pm 4.5$  %) and  $\text{VO}_2$ peak ( $52.0 \pm 8.7$  ml $\cdot$ kg $^{-1}\cdot$ min $^{-1}$ ), indicated that the subjects were well trained master athletes.

**Table 1**

Subject characteristics (n=51)

	Mean	SD	Min - Max
Age (years)	53.6	8.4	40-77
Height (cm)	175.6	6.8	160.0-192.5
Weight (kg)	72.1	8.7	49.4-99.6
Body fat (%)	17.3	4.5	7.1-25.1
Training (d $\cdot$ wk $^{-1}$ )	5.9	1.1	3-7
Training (km $\cdot$ wk $^{-1}$ )	63.8	24.7	32.2-120.7
$\text{VO}_2$ max (L $\cdot$ min $^{-1}$ )	3.75	0.67	2.26-5.08
$\text{VO}_2$ max (ml $\cdot$ kg $^{-1}\cdot$ min $^{-1}$ )	52.0	8.7	34.2-67.7
LT $_{\% \text{max}}$ (%)	70.7	10.5	46.5-90.7
Power at LT (W $\cdot$ kg $^{-1}$ )	3.82	1.05	2.35-6.47
$\text{VO}_2$ at LT (ml $\cdot$ kg $^{-1}\cdot$ min $^{-1}$ )	36.5	7.2	23.9-55.0
10 km (min)	44.0	4.6	35-54

*Correlations between metabolic data and performance* (Table 2): whereas  $\text{VO}_2$ peak ( $r = -0.56$ ,  $P < 0.001$ ), Power at LT ( $r = -0.44$ ,  $P < 0.001$ ), and  $\text{VO}_2$  at LT ( $r = -0.39$ ,  $P = 0.002$ ) were inversely correlated to 10 km performance,  $\text{LT}_{\text{rel}}$  was not correlated ( $r = 0.10$ ,  $P = 0.48$ ).



**Table 2**

Pearson correlations (r) between metabolic data and 10 km performance

	VO <sub>2</sub> max	Power at LT	VO <sub>2</sub> at LT	LT <sub>%max</sub>
10 km	-0.56*	-0.44*	-0.39*	0.10

\*significant association, P&lt;0.01

**Table 3**

Stepwise multiple regression for prediction of 10 km performance

	B	SE B	Beta
Step 1			
Constant	59.44	3.34	
VO <sub>2</sub> max	-0.30	0.06	-0.56
Step 2			
Constant	61.92	3.31	
VO <sub>2</sub> max	-0.25	0.06	-0.46
Power at LT	-1.32	0.52	-0.30

R<sup>2</sup>=0.31 for Step 1, P<0.001; ΔR<sup>2</sup>=0.08 for Step 2, P=0.015

*Correlations between metabolic data and age:* Age had positive significant correlations with LT<sub>rel</sub> (r=0.40, P=0.004) and 10 km performance time (r=0.46, P=0.001), which indicated that increased age was associated with higher LT<sub>rel</sub>, but poorer endurance performance. Age was also significantly correlated to VO<sub>2</sub>peak (r=-0.41, P=0.003). There were no significant correlations between age and either of the two absolute measures of LT, Power at LT (r=-0.05, P=0.72) and VO<sub>2</sub> at LT (r=-0.04, P=0.80). These results suggest that age may have a potentially confounding effect on the correlations between LT, VO<sub>2</sub>peak and 10 km performance. However, controlling for age with a partial order correlation did not statistically or meaningfully affect the reported associations.

*Metabolic predictors of 10 km Performance:* VO<sub>2</sub>peak, LT<sub>rel</sub>, Power at LT, and VO<sub>2</sub> at LT were evaluated as predictors of 10 km performance using stepwise multiple regressions. VO<sub>2</sub>peak (R<sup>2</sup>=0.31, P<0.001) and Power at LT (R<sup>2</sup>=0.39, P=0.015) were the only significant predictors of 10 km performance.



## Discussion

The main finding of this study was that absolute LT, not relative LT ( $LT_{rel}$ ), was a significant predictor of endurance running performance for master athletes. These results support the hypothesis that absolute LT would predict endurance performance in master athletes. Furthermore, these results supported our previous finding that the typical assessment of LT,  $LT_{rel}$ , was a poor indicator of endurance running performance for master athletes, most likely due to the confounding influence of age-related decline in  $VO_{2peak}$ .

Power at LT, a significant predictor of endurance performance in the current study, was calculated by using both the treadmill velocity and elevation. In contrast, only treadmill velocity was reported in the previous study [14] and was shown not to predict endurance performance. This difference is likely because Power at LT is a more accurate indicator of inclined running intensity than velocity at LT alone. Other studies [1,6] have reported significant relationships between velocity at LT and endurance performance in master athletes utilizing discontinuous protocols of submaximal runs on a level treadmill to determine LT. The inclusion of both elevation and speed in our calculations confirmed that LT is a significant predictor of endurance performance in male master athletes.

It is well known that  $VO_{2peak}$  decreases with aging [1,11,14]. Oxygen consumption at LT also decreases with aging, but at a slower rate than the decrease in  $VO_{2peak}$ , causing  $LT_{rel}$  to increase with age [11], irrespective of training status. The current study did not find any correlation between  $LT_{rel}$  and 10 km performance, supporting the hypothesis that  $LT_{rel}$  is not predictive of endurance performance for master athletes. However, since absolute LT was a significant predictor of 10 km performance, the dissociation between  $LT_{rel}$  and endurance performance for master athletes is most likely caused by the confounding influence of age-related decline of  $VO_{2peak}$ , not by a change in the importance of LT for determining endurance performance.

For young athletes, LT is a better predictor of endurance running performance than  $VO_{2peak}$  [6-8]. Although LT was a significant predictor in the present study,  $VO_{2peak}$  was the best predictor of endurance performance. This difference may be due to the relative heterogeneity of  $VO_{2peak}$  in the present study compared to previous research on young athletes. In the present study,  $VO_{2peak}$  ranged from 34.2 - 67.7  $ml \cdot kg^{-1} \cdot min^{-1}$ , potentially overestimating the influence of  $VO_{2peak}$  on endurance performance. There were not a sufficient number of subjects in the present study to divide the sample into groups that were homogeneous for  $VO_{2peak}$ , but LT might presumably be a better predictor of endurance performance



than  $\text{VO}_2\text{peak}$  in master athletes groups that are homogeneous for  $\text{VO}_2\text{peak}$ .

Although age was significantly correlated to endurance performance, we did not include it in our prediction model for two reasons. Firstly, the primary objective of this study was to determine whether the physiological variables that may change with age, not age per se, were significant predictors of endurance running performance. Adding age to the stepwise analysis may have veiled the affects of the other predictors. Furthermore, partial order correlations revealed that controlling for age did not alter the relationships between LT,  $\text{VO}_2\text{peak}$  and 10 km performance.

Methodological considerations that may have affected the results of this experiment have been extensively discussed in previous articles [11,14]. In brief, the LT determination protocol utilized relatively short stages which did not elicit steady state, and therefore may have reduced the accuracy of LT determination [15]. However, our LT findings are similar to the values measured in another study of master athletes <sup>1</sup>, which utilized what is widely considered the gold standard of LT determination; discontinuous 10 min runs.

It is also possible that 10 km performance, which was assessed via questionnaire, did not accurately describe maximal performance. However, the importance of these races to this population became evident after working closely with this population for a number of years. In addition to describing the performance time, athletes could describe in vivid detail the location, course layout, weather, and other aspects with clarity. Additionally, all of reported races occurred within the 4 months prior to testing, and there had been no missed training, indicating that their training status had not significantly changed since the reported performance.

Assessing performance via questionnaire has many inherent limitations such as the effects of weather, varied course difficulty, wind, and competition, compared to laboratory performance testing. However, these effects are relatively minimal during a 10 km race, resulting in approximately 2% coefficient of variance in male master athletes [9], and may more accurately describe endurance running performance than laboratory testing [10].

In conclusion, LT is predictive of endurance performance in male master athletes regardless of age-related decreases in  $\text{VO}_2\text{peak}$  when LT is expressed in absolute terms. LT expressed in relative terms should not be used as an indicator of endurance capacity in master athletes because of the confounding influence of  $\text{VO}_2\text{peak}$ .



## References

1. Allen W.K., D.R.Seals, B.F.Hurley, A.A.Ehsani, J.M.Hagberg (1985) Lactate threshold and distance-running performance in young and older endurance athletes. *J.Appl. Physiol.* 58:1281-1284
2. Amann M., A.W.Subudhi, C.Foster (2006) Predictive validity of ventilatory and lactate thresholds for cycling time trial performance. *Scand.J.Med.Sci.Sports* 16:27-34
3. Bassett D.R., Jr., E.T.Howley (2000) Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Med.Sci.Sports Exerc.* 32:70-84
4. Coyle E.F., M.E.Feltner, S.A.Kautz, M.T.Hamilton, S.J.Montain, A.M.Baylor, L.D.Abraham, G.W.Petrek (1991) Physiological and biomechanical factors associated with elite endurance cycling performance. *Med.Sci.Sports Exerc.* 23:93-107
5. Craig N.P., K.I.Norton, P.C.Bourdon, S.M.Woolford, T.Stanef, B.Squires, T.S.Olds, R.A.Conyers, C.B.Walsh (1993) Aerobic and anaerobic indices contributing to track endurance cycling performance. *Eur.J.Appl.Physiol.Occup.Physiol.* 67:150-158
6. Evans S.L., K.P.Davy, E.T.Stevenson, D.R.Seals (1995) Physiological determinants of 10-km performance in highly trained female runners of different ages. *J.Appl.Physiol.* 78:1931-1941
7. Farrell P.A., J.H.Wilmore, E.F.Coyle, J.E.Billing, D.L.Costill (1979) Plasma lactate accumulation and distance running performance. *Med.Sci.Sports* 11:338-344
8. Grant S., I.Craig, J.Wilson, T.Aitchison (1997) The relationship between 3 km running performance and selected physiological variables. *J.Sports Sci.* 15:403-410
9. Hopkins W.G., D.J.Hewson (2001) Variability of competitive performance of distance runners. *Med.Sci.Sports Exerc.* 33:1588-1592
10. Kranenburg K.J., D.J.Smith (1996) Comparison of critical speed determined from track running and treadmill tests in elite runners. *Med.Sci.Sports Exerc.* 28:614-618
11. Marcell T.J., S.A.Hawkins, K.M.Tarpenning, D.M.Hyslop, R.A.Wiswell (2003) Longitudinal analysis of lactate threshold in male and female master athletes. *Med.Sci.Sports Exerc.* 35:810-817
12. Siri W.E. (1956) Gross composition of the body. In: J.H. Lawrence (ed.) *Advances in Biological and Medical Physics*. Putnam, New York, pp. 270
13. Wilmore J.H. (1969) A simplified method for determination of residual lung volumes. *J.Appl.Physiol.* 27:96-100
14. Wiswell R.A., S.V.Jaque, T.J.Marcell, S.A.Hawkins, K.M.Tarpenning, N.Constantino, D.M.Hyslop (2000) Maximal aerobic power, lactate threshold, and running performance in master athletes. *Med.Sci.Sports Exerc.* 32:1165-1170
15. Yoshida T., M.Udo, K.Iwai, T.Yamaguchi (1993) Physiological characteristics related to endurance running performance in female distance runners. *J.Sports Sci.* 11:57-62

