INTERNATIONAL JOURNAL OF SPORTS PHYSIOLOGY AND PERFORMANCE

Elite aerobic endurance performance: is it really related to lactate threshold expressed relative to peak oxygen uptake?

Journal:	*International Journal of Sports Physiology and Performance*
Manuscript ID	IJSPP.2024-0528.R1
Manuscript Type:	Brief Report
Date Submitted by the Author:	n/a
Complete List of Authors:	Johansen, Jan - Michael; University of South-Eastern Norway - Campus Bo, Department of Sports, Physical Education and Outdoor Studies Støa, Eva; University of South-Eastern Norway - Campus Bo, Department of Sports, Physical Education and Outdoor Studies Sunde, Arnstein; University of South-Eastern Norway - Campus Bo, Department of Sports, Physical Education and Outdoor Studies; Universitetet i Sør-Øst Norge, Idrettsfysiologisk testlab, Bø Rønnestad, Bent; Inland Norway University of Applied Sciences - Lillehammer Campus, Section for Health and Exercise Physiology, Lillehammer Helgerud, Jan; University of Science and Technology, Circulation and Medical Imaging Støren, Øyvind; University of South-eastern Norway, Department of Sports, Physical Education and Outdoor Studies
Keywords:	peak oxygen uptake, endurance athletes, determinants of performance, cycling, running, cross-country skiing

Elite aerobic endurance performance: is it really related to lactate threshold expressed relative to peak oxygen uptake?

Brief report

Jan – Michael Johansen[1]*, Eva Maria Støa[1], Arnstein Sunde[1], Bent R. Rønnestad[2], Jan Helgerud[3,4], Øyvind Støren[1,5].

[1] Department of Sports, Physical Education and Outdoor Studies, University of South-Eastern Norway, Bø, Norway, [2] Section for Health and Exercise Physiology, Institute of Public Health and Sport Sciences, Inland Norway University of Applied Sciences, Lillehammer, Norway, [3] Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Trondheim, Norway, [4] Myworkout, Medical Rehabilitation Centre, Trondheim, Norway, [5] Department of Natural Sciences and Environmental Health, University of South-Eastern Norway, Bø, Norway.

*Corresponding author
Dr. Jan – Michael Johansen
University of Southeastern Norway
Gullbringvegen 36
3800 Bø, Norway
+47 35 95 26 83
jan-michael.johansen@usn.no

Running head: Lactate threshold in endurance athletes.

Abstract word count: 235

Text-only word count: 1413

No. figures/tables: 3

Elite aerobic endurance performance: is it really related to lactate threshold expressed relative to peak oxygen uptake?

Brief report

Jan – Michael Johansen[1]*, Eva Maria Støa[1], Arnstein Sunde[1], Bent R. Rønnestad[2], Jan Helgerud[3,4], Øyvind Støren[1,5].

[1] Department of Sports, Physical Education and Outdoor Studies, University of South-Eastern Norway, Bø, Norway, [2] Section for Health and Exercise Physiology, Institute of Public Health and Sport Sciences, Inland Norway University of Applied Sciences, Lillehammer, Norway, [3] Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Trondheim, Norway, [4] Treningsklinikken~~Myworkout~~, Medical Rehabilitation Clinic~~entre~~, Trondheim, Norway, [5] Department of Natural Sciences and Environmental Health, University of South-Eastern Norway, Bø, Norway.

*Corresponding author
Dr. Jan – Michael Johansen
University of Southeastern Norway
Gullbringvegen 36
3800 Bø, Norway
+47 35 95 26 83
jan-michael.johansen@usn.no

Running head: Lactate threshold in endurance athletes.

Abstract word count: 235

Text-only word count: 1662~~413~~

No. figures/tables: 3

Abstract

Purpose: The purpose of this study was to investigate how lactate threshold, expressed as a percentage ($LT_{\%}$) of peak oxygen uptake (VO_{2peak}), is related to aerobic endurance performance in a large group of aerobic endurance athletes from three demanding aerobic endurance sports.

Methods: 292 (212 males and 80 females) aerobic endurance athletes competing in long distance running, cycling and cross-country skiing participated in the present study. Based on their competitive history, they were divided into three performance level groups: elite (n=71), national (n=158), and regional performance level (n=63). VO_{2peak} and LT tests were conducted on the same day for all athletes, with similar testing protocols.

Results: In the large group of endurance athletes, $LT_{\%}$ did not differ between performance levels (78.9±6.4%, 79.9±6.7%, and 80.3±7.1% for elite, national and regional level, respectively). The same non-significant difference was observed within males and females as well. VO_{2peak} differed significantly ($p<0.01$) between performance levels (71.1±6.5, 65.5±8.0, and 58.1±6.4 $mL \cdot kg^{-1} \cdot min^{-1}$ in elite, national and regional level, respectively). This was also displayed within males and females separately, although not when expressed in $L \cdot min^{-1}$.

Conclusions: The findings of similar $LT_{\%}$ between different performance levels in the large group of endurance athletes challenges the realm of $LT_{\%}$ being considered as one of the primary determinants of aerobic endurance performance. This study also confirms the importance of VO_{2peak} as a primary predictor of aerobic endurance performance in a large group of aerobic endurance athletes.

Keywords: peak oxygen uptake, endurance athletes, determinants of performance, running, cycling, cross-country skiing.

Introduction

Lactate threshold (LT) is considered as one of the primary predictors of aerobic endurance performance alongside work economy (C) and peak oxygen uptake (VO_2peak)[1]. LT is commonly defined as the highest exercise intensity where the lactate production and removal is balanced[2]. Most often, LT is expressed relative to VO_{2peak}, i.e., as a percentage ($LT_{\%}$), and is seen to vary between 75-90% of VO_2peak in trained individuals[1]. $LT_{\%}$ is also expected to be higher in endurance athletes performing at a higher performance level, i.e., the elite level[1,] and therefore suggested as an important determinant of aerobic endurance performance. On the other hand, several studies do not reveal significant improvements in $LT_{\%}$ by different training regimes in already trained individuals[3-5]. In addition, previous studies of aerobic endurance athletes find no relationships between $LT_{\%}$ and endurance performance[6,7]. These findings challenge the notion that $LT_{\%}$ is an aerobic performance determinant in aerobic endurance sports.

When LT is expressed as a workload (LT_W), such as a specific velocity or wattage, studies have reported a strong relationship to aerobic endurance performance[6,7]. Training interventions often show that adaptations in LT_W occur concurrently with improvements in VO_2peak or C[3-5,8]. These two aerobic variables are also key determinants of maximal aerobic speed (MAS), as MAS can be calculated as VO_2peak divided by C[6,7]. Among endurance athletes, LT_W has been shown to be strongly dependent on MAS[9-11].

Previous studies addressing the relationship between $LT_{\%}$ and endurance performance have typically small cohorts of participants and are often limited to a single sport. Stronger evidence would be provided if the same relationships were demonstrated in a larger cohort of aerobic endurance athletes in different aerobic endurance sports. The purpose of the present study was therefore to investigate the extent to which $LT_{\%}$ is related to aerobic endurance performance level in a large cohort of endurance athletes participating in long distance running, cycling and cross-country skiing. Our hypothesis was that $LT_{\%}$ would be similar across performance level groups, and that VO_2peak would increase with higher performance levels.

Methods

Design

The present study has a cross-sectional design, with most of the data previously published in Støren et al.[9], Støa et al.[10], and Johansen et al.[11], although with different research objectives compared to the present study. In addition, non-published data (n=15 cyclists) have been added to increase the total number of participants. VO_2peak~~max~~ and LT tests were performed on the same day for all participants.

Participants

292 aerobic endurance athletes (212 Males and 80 females) were included in this study. The athletes were competing in three different aerobic endurance sports (75 long-distance runners, 123 road cyclists, and 94 cross country skiers). They were categorized into three different performance level groups based on their competition history. Elite athletes (N=71) were defined as competing at an international level (e.g., World, European, or Nordic cups at either senior or junior level). National level (N=158) was defined as competing at a national level (e.g., national cups at either senior or junior level). Regional level (N=63) was defined as competing at any level, most often in regional recreational competitions. Training history was

not thoroughly registered for all athletes, however all athletes were well-trained. Elite level athletes generally had a higher total training volume (15 – 25 $h \cdot week^{-1}$) compared to national and regional level athletes.

The participants received both oral and written information about the nature of the original study before they gave their written informed consent. All original studies were conducted in accordance with the Declaration of Helsinki. The original studies were either approved by the regional ethical committee of Southeast Norway[9,11] or approved by the ethical board at University of South-Eastern Norway (USN) (all studies).

Test protocols and materials

The majority of tests were conducted at USN, and some were conducted at either Inland Norway University of Applied Sciences (INN), at the Norwegian School of Sport Sciences (NSSS), or at the Norwegian University of Science and Technology (NTNU). The equipment used at the different laboratories were validated against each other repeatedly. Test protocols were identical in the different laboratories, for the same sports. For a detailed description of test protocols and test materials in each sport, please see Støren et al.[9], Støa et al.[10] and Johansen et al.[11].

Statistics

The data material was found to be normally distributed for both LT and VO_2peak~~max~~ by use of Kolmogorov – Smirnov tests, and parametric statistics were therefore used. Data were presented descriptively, and comparisons between groups were done by independent sample t-tests (sex) or general linear model - tests (competition level). All statistical analysis were performed by SPSS version 29.1, and the significance level was set to $p<0.05$ in two-tailed tests.

Results

Characteristics of all participating athletes in total, divided by endurance sport and by sex are presented in Table 1.

Table 1

Differences in $LT_{\%}$ and VO_2peak ($mL \cdot kg^{-1} \cdot min^{-1}$) between the different performance levels are presented in Figure 1 (A-C) and Figure 2 (A-C).

Figure 1

Figure 2

Elite level athletes had significantly higher VO_2peak expressed in $L \cdot min^{-1}$ compared to national and regional level athletes (5.20±0.74 vs. 4.69±0.82 and 4.11±0.81 respectively, all $p<0.01$), and national level athletes had higher values compared to regional level athletes ($p<0.01$). These differences were also present in the males, although not for females. No significant differences were observed in body weight between performance levels in the whole sample, nor in males or females.

Discussion

The main findings of the present study were that $LT_{\%}$ did not differ between a large group of aerobic endurance athletes representing elite, national and regional performance levels.

The novelty of this study is the investigation of nearly 300 aerobic endurance athletes at different performance levels, representing three demanding endurance sports. In the present study, $LT_{\%}$ ranged similarly to that reported in elite endurance athletes by Joyner and Coyle[1]. However, the same range was observed in national and regional athletes, with some athletes with a $LT_{\%}$ at □90% of VO_2peak in all performance groups (Figure 1). The finding of no differences in $LT_{\%}$ between elite, national and regional endurance athletes in the present study aligns with the results in previous research[9,10,12]. This is also in line with experimental studies struggling to find significant adaptations in $LT_{\%}$ with training[3-5]. On the other hand, the notion that $LT_{\%}$ seems to be higher in elite endurance athletes compared to athletes at a lower level[1], is not supported by the results of the present study. T~~he findings of this study, t~~herefore, these findings challenges $LT_{\%}$ being an important determinant of aerobic endurance performance, and the idea that this LT characteristic is an important contributor to performance VO_2[1]~~.~~

Although t~~T~~he present results suggest that $LT_{\%}$ is a poor indicator to differentiate performance levels in aerobic endurance athletes, this is a suggestion that should be treated with some caution. First, t~~T~~his does not necessarily mean that a high $LT_{\%}$ could not be an advantage in endurance sports, ~~but~~ although it does not discriminate performance in the present study, nor~~it does not~~ seem to be highly trainable[3-5]. ~~If $LT_{\%}$ were trainable, we could have expected that elite athletes were superior to national and regional level athletes in this variable. In addition, previous research has revealed that $LT_{\%}$ is a poor indicator of LT_W as well[9-11].~~ Secondly, by combining results from three different endurance sports, we are able to see the two variables VO_2peak and $LT_{\%}$ in a wider context, but this combination also excludes the sports-specific variables, e.g., C and LT_W, and thus also MAS. However, these variables were accounted for in the three original studies preceding the present one[9,10,11]. In these three studies, each of the three sports were investigated separately, showing the same results regarding VO_2peak and LT% as in the present study, and also that C, MAS and LT_W were highly associated with performance level. ~~Contrary to $LT_{\%}$,~~ LT_W has~~ve~~ been reported to be a good indicator of aerobic endurance performance[6,7], and adaptations in LT_W are observed together with adaptations in MAS[3-5,8]. LT_W is, in theory, majorly determined by VO_2 at LT and C[1], and it have been observed that LT_W is primarily determined by MAS[9-11]. Thirdly, it could be argued that while VO_2peak would be most crucial for performance in shorter endurance events like the 5000m running, LT% would be more critical in e.g. marathoners[13,14]. Even with nearly 300 athletes in the present study, the material was too small to divide in both performance groups and in different events in e.g., long - distance running. However, most of the elite runners in the present study competed mainly in 5000m and 10000m, and most of the elite cyclists were allrounders, competing in both time trials and road – races. As long as all athletes did not compete in the same events with the approximate same durations, we cannot categorically rule out that the results to some extent could be prone to the heterogeneity in event duration.

In the present study, as well as in Støren et al.[9] and Støa et al.[10], VO_{2peak} was significantly higher in elite compared to national athletes, and in national compared to regional athletes. This was not surprising as the importance of VO_{2peak} for aerobic endurance performance across different sports and performance levels is well documented at a group level[1,7,15~~2~~]. This also aligns with the idea that VO_2peak is a major contributor to performance VO_2, and thus aerobic endurance performance, proposed by Joyner and Coyle[1]. Several previous studies have also shown improved VO_2peak and/or improved C, accompanying improvements in aerobic endurance performance[3-5,8]. However, as depicted in Figure 2, performance levels might be difficult to differentiate based solely on VO_2peak at an individual level, also supported by Joyner and Coyle[1]. In these cases, other physiological determinants become more important, such as C[1].

Practical implications

Based on the present results, and also the three preceding studies on each separate sport, ~~targeting adaptations in $LT_{\%}$ as a sole objective after training periods seems questionable, since $LT_{\%}$ did not differ between performance levels. In addition, since other LT characteristics, such as LT_W, are highly dependent on MAS[6-11],~~ we recommend training focus~~ing most on~~ to improve MAS, i.e., improvind VO_2peak and, or C. ~~and less on LT in evaluating and training aerobic endurance athletes.~~ The present results may also call for a re-evaluation of $LT_{\%}$ as a primary determinant of aerobic endurance performance.

Conclusions

No differences were observed in $LT_{\%}$ between large groups of elite, national and regional endurance athletes. This suggests that $LT_{\%}$ is a poor predictor of performance in aerobic endurance sports. This study also confirms the importance of VO_2peak as a primary predictor of aerobic endurance performance in a large group of aerobic endurance athletes.

Acknowledgements

We would like to thank all participating athletes for their great contribution and their cooperation with this study. We also would like to thank all bachelor- and master students helping out with the extensive data collection. No external funding was provided for this research. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Joyner MJ, and Coyle EF. Endurance exercise performance: The physiology of champions. *J Physiol.* 2008 Jan;586(1):35–44. Doi: 10.1113/jphysiol.2007.143834.
2. Heuberger JAAC, Gal P, Stuurman FE, de Muinck Keizer WAS, Mejia Miranda Y, Cohen AF. Repeatability and predictive value of lactate threshold concepts in endurance sports. *PLoS One.* 2018 Nov;13(11):e0206846. Doi: 10.1371/journal.pone.0206846.
3. Enoksen E, Shalfawi SA, Tønnessen E. The effect of high- vs. low-intensity training on aerobic capacity in well-trained male middle-distance runners. *J Strength Cond Res.* 2011 Mar;25(3):812-8. Doi: 10.1519/JSC.0b013e3181cc2291.
4. Rønnesatd BR, Hansen J, Thyli V, Bakken TA, Sandbakk Ø. 5-week block periodization increases aerobic power in elite cross-country skiers. *Scand J Med Sci Sports.* 2016 Feb;26(2):140-6. Doi: 10.1111/sms.12418.
5. Sylta Ø, Tønnessen E, Hammarström D, Danielsen J, Skovereng K, Ravn T, Rønnestad BR, Sandbakk Ø, Seiler S. The Effect of Different High-Intensity

Periodization Models on Endurance Adaptations. *Med Sci Sports Exerc.* 2016 Nov;48(11):2165-74. Doi: 10.1249/MSS.0000000000001007.

6. McLaughlin JE, Howley ET, Bassett Jr, DR, Thompson DL, Fitzhugh EC. Test of the classic model for predicting endurance running performance. *Med Sci sports Exerc.* 2010 May;42(5):991-7. Doi: 10.1249/MSS.0b013e3181c0669d.
7. Støren Ø, Ulevåg K, Larsen MH, Støa EM, and Helgerud J. Physiological determinants of the cycling time trial. *J Strength Cond Res.* 2013 Sep;27(9):2366-73. Doi: 10.1519/JSC.0b013e31827f5427.
8. Stöggl T, Sperlich B. Polarized training has greater impact on key endurance variables than threshold, high intensity, or high volume training. *Front Physiol.* 2014 Feb 4;5:33. Doi: 10.3389/fphys.2014.00033.
9. Støren Ø, Rønnestad BR, Sunde A, Hansen J, Ellefsen S, and Helgerud J. A time-saving method to assess power output at lactate threshold in well-trained and elite cyclists. *J Strength Cond Res.* 2014 Mar;28(3):622-9. Doi: 10.1519/JSC.0b013e3182a73e70.
10. Støa EM, Helgerud J, Rønnestad BR, Hansen J, Ellefsen S, and Støren Ø. Factors Influencing Running Velocity at Lactate Threshold in Male and Female Runners at Different Levels of Performance. *Front Physiol.* 2020 Nov;11:585267. Doi: 10.3389/fphys.2020.585267.
11. Johansen JM, Sunde A, Helgerud J, Støren Ø. Relationships Between Maximal Aerobic Speed, Lactate Threshold, and Double Poling Velocity at Lactate Threshold in Cross-Country Skiers. *Front Physiol.* 2022 Feb 28;13:829758. Doi: 10.3389/fphys.2022.829758.
12. Farrell PA, Wilmore JH, Coyle EF, Billing JE, and Costill DL. Plasma lactate accumulation and distance running performance. *Med Sci Sports Exerc.* 1979 Winter; 11(4):338-44.
13. Jones AM, Kirby BS, Clark IE, Rice HM, Fulkerson E, Wylie LJ, Wilkerson DP, Vanhatalo A, and Wilkins BW. Physiological demands of running at 2-hour marathon race pace. *J Appl Physiol* (1985). 2021 Feb 1;130(2):369-379. Doi: 10.1152/japplphysiol.00647.2020.
14. Rabadán M, Díaz V, Calderón FJ, Benito PJ, Peinado AB, and Maffulli N. Physiological determinants of speciality of elite middle- and long-distance runners. *J Sports Sci.* 2011 Jun;29(9),975–82. Doi: 10.1080/02640414.2011.571271.

~~11.~~

~~12.~~15. Stöggl T, Pellegrini B, Holmberg, H-C. Pacing and predictors of performance during cross-country skiing races: A systematic review. *J Sport Health Sci.* 2018 Oct;7(4): 381-93. Doi: 10.1016/j.jshs.2018.09.005.

Figure legends

Figure 1 – Differences in LT$_{\%}$ between athletes' performance levels. The figure display differences in A) the whole group, B) in males, and C) in females in athletes representing an elite, national or regional performance level. Individual data are represented as dots.

Figure 2 – Differences in VO_{2peak} ($mL \cdot kg^{-1} \cdot min^{-1}$) between athletes' performance levels. The figure display differences in A) the whole group, B) in males, and C) in females in athletes representing an elite, national or regional performance level. Individual data are represented as dots. * $p<0.05$ significantly different from regional level. ** $p<0.01$ significantly different from regional level. ## $p<0.01$ significantly different from national level. §§ $p<0.01$ significantly different from elite level.

Table 1. Subject characteristics for all participants, performance levels and sex.

		Aerobic endurance sport			*Sex differences*	
	All n = 292	Cyclists n = 123	Runners n = 75	XC skiers n = 94	Males n=212	Females n = 80
Sex (m/f)	212/80	111/12	37/38	64/30	-	-
BW	71.7±9.8	74.6±5.9	67.0±11.0†§	71.3±8.3	75.3±7.8	62.0±7.5**
VO_{2peak}						
$ml \cdot kg^{-1} \cdot min^{-1}$	65.3±8.5	66.6±5.3	63.0±9.3	65.5±8.3	68.1±7.5	57.9±6.4**
$L \cdot min^{-1}$	4.69±0.88	4.94±0.45$^{\#}$	4.20±1.00†§	4.70±0.89$^{\#}$	5.11±0.58	3.59±0.48**
$LT_{\%}$	79.7±6.7	76.1±8.9$^{\#§}$	83.6±4.0†	81.4±6.7†	78.5±6.7	82.7±5.7**

Values are presented as mean ± standard deviation (SD). XC, cross-country skiers. M, males. F, females. BW, body weight. VO_{2peak}, peak oxygen uptake. $ml \cdot kg^{-1} \cdot min^{-1}$, milliliters per kilogram bodyweight per minute. $L \cdot min^{-1}$, liters per minute. $LT_{\%}$, lactate threshold in percentage of peak oxygen uptake.

$^{†}p<0.05$ significantly different from cycling.

$^{\#}p<0.05$ significantly different from running.

$^{§}p<0.05$ significantly different from XC skiing.

$^{**}p<0.01$ significantly different from males.

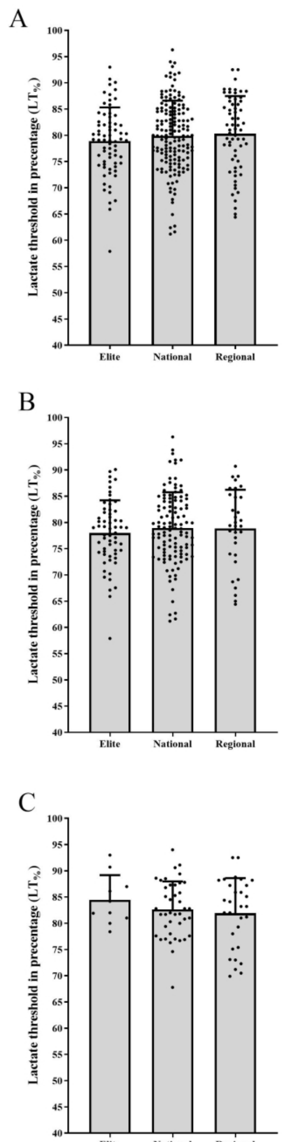

Figure 1 – Differences in $LT_{\%}$ between athletes' performance levels. The figure display differences in A) the whole group, B) in males, and C) in females in athletes representing an elite, national or regional performance level. Individual data are represented as dots.

73x254mm (300 x 300 DPI)

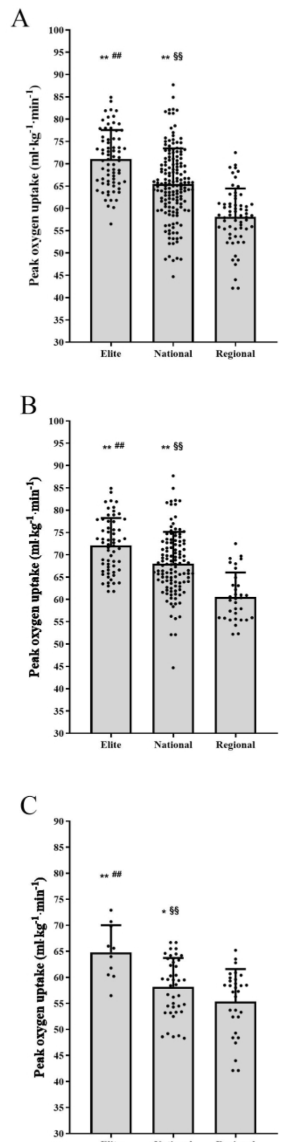

Figure 2 – Differences in VO_{2peak} ($mL \cdot kg^{-1} \cdot min^{-1}$) between athletes' performance levels. The figure display differences in A) the whole group, B) in males, and C) in females in athletes representing an elite, national or regional performance level. Individual data are represented as dots.

72x256mm (300 x 300 DPI)