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Original article

Calculating lactate anaerobic thresholds in sports involving different endurance preparation

Arkadiusz Stanula [a,*], Tomasz Gabrys [b], Urszula Szmatlan-Gabrys [b], Robert Roczniok [a], Adam Maszczyk [a], Przemysław Pietraszewski [a]

[a] The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland
[b] Academy of Physical Education, Krakow, Poland

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Abstract

The aim of this study was to establish the degree of similarity of exercise intensity values at the anaerobic threshold (AT) provided by five methods of lactate curve analysis, i.e., LT_{AT}, LT_{loglog}, 1 mmol AT, 4 mmol AT, and D-max. The pattern of similarities and differences was sought in athletes with varying levels of experience and sports skills, representing two disciplines with different prevailing types of power output during competition: on-road cycling (aerobic metabolism) and ice-hockey (anaerobic metabolism).

All groups of athletes tested [Group 1: on-road cyclists ($n = 19$) at international sporting level (participants of the Olympic Games and World Championships); Group 2: on-road cyclists ($n = 20$) at national sporting level; Group 3: ice-hockey players ($n = 24$) at international sporting level (Polish National Team); and Group 4: ice-hockey players ($n = 22$) at international sporting level (Polish National Team U-20)] performed an incremental exercise.

The greatest power values at the anaerobic threshold (PAT) were provided by the LT_{AT} (221.93 $\pm$ 34.5 W) and 4 mmol AT (226.38 $\pm$ 32.33 W) methods, whereas the lowest were provided by the LT_{loglog} (190.71 $\pm$ 25.92 W) method. The PAT produced by the LT_{loglog} method was statistically significantly lower ($p \leq 0.001$) than the values provided by LT_{AT}, 4 mmol AT, and D_{max}. The PAT levels were found to be statistically significantly different for power values determined using the 4 mmol AT and those produced by the 1 mmol AT ($p \leq 0.001$) and D-max ($p \leq 0.01$) methods. As shown by the analyses, PAT values vary in the international-level on-road cyclists depending on the method of lactate curve analysis applied.

Keywords: Anaerobic threshold; Endurance training; Lactate threshold

Introduction

Aerobic−anaerobic thresholds sought using methods that analyze changes in lactate concentration kinetics during incremental exercise are commonly used in athletic training as indicators of an athlete's endurance, preparedness, and training load parameters.[39] The point where a lactate curve shows characteristic changes is known as an anaerobic threshold (AT), the lactate threshold (LT), the onset of blood lactate accumulation (OBLA), a maximal lactate steady state (MLSS), and a 4 mmol critical threshold.[61] As an indicator of changes in endurance, the anaerobic threshold parameters sought by studies mostly concentrate on endurance athletes, such as cyclists,[31,37] long-distance runners,[44,51] triathletes,[30] cross-country ski runners,[24,45,55] canoeing[43] and rowing.[5,10] The level and dynamics of changes in the anaerobic threshold that take place during training have also been studied in many other disciplines, such as football,[23] basketball,[14,29] ice-hockey[19] and judo.[57] Being able to determine

* Corresponding author. The Jerzy Kukuczka Academy of Physical Education, Mikolowska 72A, 40-0656 Katowice, Poland.
E-mail address: a.stanula@awf.katowice.pl (A. Stanula).

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exactly what intensity of an athlete's exercise involves mainly anaerobic metabolism is a very important element of planning athletic training as well as being crucial for selecting training volume and intensity.[8] The basic method that seeks the anaerobic threshold (AT) level based on the kinetics of blood lactate concentration (LA) during incremental exercise is an exponential method (LA_{AT}) that was described by Lundberg et al (1986)[46] and approved for incremental exercise tests by Hughson et al (1987).[36] The method assumes that a set of LA values can be described with respect to exercise intensity using an exponential model (a continuous method). The AT is determined as a projection of the point where the exponential (lactate) curve intersects its tangent drawn at 45° onto intensity axis. Beaver et al (1985)[4] showed that taking the logarithms of load and LA values offers a more precise identification of exercise intensity at the AT. Known as LT_{loglog}, their method finds the AT value where the LA points start deviating upwards from the values lying along a straight regression line representing changes taking place under exercise intensity below the AT. Where this straight line intersects the regression line for quickly increasing values is recorded as the AT. The practical application of both these methods in training practice was described by Saar (1986)[56] based on tests involving ski runners. The relationship between a nonlinear LA growth and exercise intensity was noted by Ivy et al (1980),[38] who determined the limit values of exercise intensity on this basis. This concept of exercise intensity assessment was used by Coyle et al (1983),[21] who assumed that the exercise intensity at the AT level made lactate concentration increase by 1 mmol l^{-1}. This method was named 1 mmol AT. Karlson and Jacobs (1982)[42] assumed as a standard that 4 mmol l^{-1} corresponds to exercise intensity at the lactate threshold. Lactate curve analyses performed by Heck et al (1985)[34] showed that it was rational to assume that a value making lactate concentration grow in excess of 4 mmol l^{-1} (4 mmol AT) could be taken as exercise intensity at the AT. Cheng et al (1992)[15] proposed a different approach to lactate curve analysis aimed at determining the AT threshold (D-max). This method assumes that exercise intensity at the AT is given by a projection on the intensity axis drawn from a point situated on the section linking the extreme points of the lactate curve on the most distant point from that curve.

Each of the above methods of lactate curve analysis requires a graded incremental exercise test[27,49] to assess changes in aerobic endurance performance capacity.[25] The similarity of the requirements applying to the exercise test procedures in all these methods enables comparisons of exercise intensity parameters at the AT level. The methods used for determining the AT were compared in the studies by Brooks (1985), Heck et al (1985), Lundberg et al (1986), Svedahl and MacIntosh (2003), and McGehee et al (2005).[11,34,46,48,61] There are no studies, however, dealing with the compatibility of methods when athletes representing the same sports discipline but with different training experience and sports skills are tested. Comparative analyses of a single method using lactate kinetics to determine the AT in athletes in disciplines varying in terms of the type of effort (endurance sports, speed-endurance sports) are not available either.

This study aimed to establish the degree of similarity of exercise intensity values at the AT provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15] The pattern of similarities and differences was sought in athletes with varying levels of experience and sports skills, representing two disciplines with different prevailing types of power output during competition: on-road cycling (aerobic metabolism) and ice-hockey (anaerobic metabolism).

Methods

Participants

Four groups of male athletes with different sports skills and training experience as well as athletic specialization (on-road cyclists and ice hockey players) were selected. Group 1 consisted of on-road cyclists ($n = 19$) at international sporting level (participants of the Olympic Games and World Championships), with a mean ± standard deviation (SD) age of 24.9 (±4.1) years, height of 1.78 (±0.42) m, body mass of 67.1 (±2.2) kg, body fat 8.3% (±2.3%), maximal oxygen uptake of 78.2 (±3.2) mL kg^{-1} min^{-1}, training experience 13 (±1.5) years. Group 2 were on-road cyclists ($n = 20$) at national sporting level. These men had a mean (±SD) age of 19.8 (±0.7) years, height 1.77 (±0.37) m, body mass 58.6 (±3.1) kg, body fat 8.9% (±1.9%), maximal oxygen uptake 67.2 (±3.2) ml kg^{-1} min^{-1}, and training experience of 8.6 (±1.8) years. Group 3 consisted of ice-hockey players ($n = 24$) at international sporting level (Polish National Team), with a mean (±SD) age of 25.8 (±3.6) years, body mass 84.8 (±5.1) kg, height 181.9 (±7.7) cm, body fat 17.3% (4.4%), maximal oxygen uptake 56.2 (±4.2) ml kg^{-1} min^{-1}, and training experience of 14–18 years. Group 4 were ice-hockey players ($n = 22$) at international sporting level (Polish National Team U-20), with a mean (±SD) age of 19.4 (±0.7) years, body mass 79.8 (±4.2) kg, height 184.9 (±4.4) cm, body fat 15.4% (3.3%), maximal oxygen uptake 58.3 (4.1) ml kg^{-1} min^{-1}, and training experience of 8–10 years. After being informed about the study and test procedures, and any possible risks and discomfort that might ensue, their written informed consent to participate was obtained in accordance with the Helsinki Declaration (2000).[66]

Research method

All groups of athletes tested performed an incremental exercise.[60] The on-road cyclists (Group 1 and Group 2) and the ice-hockey players (Group 3 and Group 4) exercised on the exercise intensity values at the AT. The initial load of 1 W kg^{-1} b.m. grew incrementally by 0.5 W kg^{-1} b.m every 3 minutes. During the final 30 seconds of each step, a sample of 20 μL of arterial blood was taken from the individual's ear lobe so that lactate concentration could be established. The lactate concentration values were recorded using reagents

Table 1
PAT values in the on-road cyclists yielded by different methods of lactate curve analysis (Group 1).

Methods of estimation AT	Power on anaerobic threshold (PAT, Watt)			
	Mean	±SD	Min	Max
LT_{AT}	221.93	34.50	175.07	313.33
LT_{loglog}	190.71	25.92	134.29	252.14
4 mmol AT	226.38	32.33	163.07	305.15
1 mmol AT	207.10	31.63	128.57	285.01
D-max	214.38	24.55	162.05	253.60

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15]

provided by EKF Diagnostics, Germany, and a lactate analyzer Biosen S-line (EKF Diagnostics, Germany). The lactate curve was analyzed with software for calculating blood lactate endurance markers.[50] The LT_{AT}, LT_{loglog}, 1 mmol AT, 4 mmol AT, and D-max methods were used to identify exercise intensity at the AT level. Due to the sizes of training loads, the power values in Group 1 and Group 2 (on-road cyclists) were calculated as absolute values (W) and Group 3 and Group 4 (ice-hockey players) as relative values with respect to body mass (W kg^{-1} b.m.).

Statistical analysis

Variables' values at the AT calculated using various methods were compared using a Student paired *t* test. Correlation coefficients between two variables were also calculated for each time of the day using a Pearson-product moment correlation matrix. One-way analysis of variance for repeated measures with Tukey *post-hoc* tests was used to compare the data obtained at different times of day. Statistical significance was accepted at $p < 0.05$.

Results

Table 1 presents the power values at the AT level for Group 1 subjects. The greatest power values at the anaerobic threshold (PAT) were provided by the LT_{AT} (221.93 ± 34.5 W) and 4 mmol AT (226.38 ± 32.33 W) methods, whereas the lowest were found by the LT_{loglog} (190.71 ± 25.92 W) method. Table 2 shows the levels of significance calculated for the differences between PAT values yielded by the different methods in the group of international-level on-road cyclists. The PAT produced by the LT_{loglog} method was statistically significantly lower ($p \leq 0.001$) than the values provided by LT_{AT}, 4 mmol AT, and D-max methods. The PAT levels were found to be statistically significantly different for power values determined using the 4 mmol AT compared to those produced by the 1 mmol AT ($p \leq 0.001$) and D-max ($p \leq 0.01$) methods. As shown by the analysis, PAT values vary in the international-level on-road cyclists depending on the method of lactate curve analysis applied.

Table 2
Significance levels characterizing the differences between PAT values in the on-road cyclists yielded by different methods of lactate curve analysis (Group 1).

Differences and significance levels				
Methods	LT_{loglog}	4 mmol AT	1 mmol AT	D-max
LT_{AT}	6.814	−1.576	3.644	1.865
p	0.001	n.s.	0.001	n.s.
	LT_{loglog}	−6.439	−2.658	−6.277
	p	0.001	n.s.	0.001
		4 mmol AT	11.115	2.824
		p	0.001	0.01
			1 mmol AT	−1.414
			p	n.s.

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15] n.s. = not significant.

Table 3
Correlations between power values at the anaerobic threshold in the on-road cyclists (Group 1) yielded by different methods of lactate curve analysis.

Correlations and significance levels				
Methods	LT_{loglog}	4 mmol AT	1 mmol AT	D-max
LT_{AT}	0.724	0.906	0.799	0.798
p	0.001	0.001	0.001	0.001
	LT_{loglog}	0.530	0.394	0.700
	p	0.005	0.05	0.001
		4 mmol AT	0.961	0.731
		p	0.001	0.001
			1 mmol AT	0.572
			p	0.005

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15]

Table 3 presents the coefficients of correlation between PAT values in the on-road cyclists in Group 1 that were found using different methods. Statistically significant correlations (from $p \leq 0.001$ to $p \leq 0.005$) were established in all cases. The correlation analysis shows that in the group of international-level cyclists, the PAT values maintain constant correlations regardless of the method used to determine the AT.

Tables 4 and 5 present PAT values in the national-level cyclists (Group 2) provided by different methods of lactate curve analysis and the levels of significance of the differences between the values. The greatest PAT values in Group 2 were yielded, as in Group 1, by LT_{AT}, 4 mmol AT, and D-max (from 178.92 ± 31.64 W to 195.38 ± 44.2 W). Statistically

Table 4
Power values at the anaerobic threshold in the on-road cyclists yielded by different methods of lactate curve analysis (Group 2).

Methods of estimation AT	Power on anaerobic threshold (PAT, Watt)			
	Mean	±SD	Min	Max
LT_{AT}	178.92	31.64	135.90	251.10
LT_{loglog}	151.50	25.92	112.17	200.34
4 mmol AT	183.55	19.00	144.72	232.21
1 mmol AT	166.51	20.43	118.51	221.16
D-max	195.38	44.20	143.37	299.60

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15]

Table 5
Significance levels characterizing the differences between power values at the anaerobic threshold in the on-road cyclists yielded by different methods of lactate curve analysis (Group 2).

	Differences and significance levels			
Methods	LT_{loglog}	4 mmol AT	1 mmol AT	D-max
LT_{AT}	7.312	−1.058	2.092	−1.399
p	0.001	n.s.	0.05	n.s.
	LT_{loglog}	−6.758	−2.455	−4.126
	p	0.001	0.05	0.001
		4 mmol AT	8.266	−1.220
		p	0.001	n.s.
			1 mmol AT	−3.058
			p	0.005

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15]

significant differences (ranging from $p \leq 0.001$ to $p \leq 0.005$) between PAT values were again observed for the LT_{loglog} and 1 mmol AT methods (151.5 ± 25.92 W and 166.51 ± 20.43 W, respectively). The pattern of the method-related variations in PAT values is similar to that observed in Group 1 (cyclists competing at international level).

Table 6 characterizes the correlations between power values obtained at the AT in the cyclists in Group 2 using different methods of lactate curve analysis. Only the 4 mmol AT method was found to provide PAT values that were significantly correlated with those produced by all other methods. A correlation was also found between PAT values obtained using the LT and LT_{loglog} methods.

The correlation analysis shows no constant correlations between PAT values in Group 2 (the national-level cyclists) depending on the method applied. Only PAT values produced by the 4 mmol AT method and those yielded by all other methods showed similar intragroup correlation.

Regarding the ice-hockey players (Group 3), the LT_{loglog} method offered the lowest PAT (2.19 ± 0.47 W kg^{-1}), whereas the 4 mmol AT method produced the greatest PAT (3.08 ± 0.32 W kg^{-1}) (Table 7). PAT values yielded by the LT_{AT} and 1 mmol AT methods were not found to be statistically different (Table 8). The statistical significance of the

Table 6
Correlations between power values at the anaerobic threshold in the on-road cyclists (Group 2) yielded by different methods of lactate curve analysis.

	Correlations and significance levels			
Methods	LT_{loglog}	4 mmol AT	1 mmol AT	D-max
LT_{AT}	0.858	0.649	0.257	−0.065
p	0.001	0.005	n.s	n.s.
	LT_{loglog}	0.459	0.107	0.074
	p	0.05	n.s.	n.s.
		4 mmol AT	0.835	0.122
		p	0.001	n.s.
			1 mmol AT	0.158
			p	n.s.

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15] n.s. = not significant.

Table 7
Power values at the anaerobic threshold in the on-road cyclists yielded by different methods of lactate curve analysis (Group 3).

Methods of estimation AT	Power on anaerobic threshold (PAT, Watt)			
	Mean	±SD	Min	Max
LT_{AT}	2.90	0.48	1.70	3.81
LT_{loglog}	2.19	0.47	1.23	3.13
4 mmol AT	3.08	0.32	2.22	3.53
1 mmol AT	2.80	0.38	1.85	3.26
D-max	2.90	0.48	1.70	3.81

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15]

differences between PAT values provided by the other methods ranged from $p \leq 0.05$ to $p \leq 0.001$.

Statistically significant correlations between PAT values derived from different methods (excluding LT_{loglog}) were found for D-max (from $p \leq 0.05$ to $p \leq 0.001$) and 1 mmol AT and 4 mmol AT ($p \leq 0.001$) (Table 9). These results point to the non-repeatability of AT parameters produced by different methods. In seeking the AT parameters, the selected method affects the value recorded. The intragroup diversity of PAT values in the team members arises from the method of lactate curve analysis applied.

PAT analysis performed in Group 4 (ice-hockey players with a shorter training experience) revealed statistically significant variations in the parameter's values that were related to the method used. The greatest PAT values were yielded, as in Group 3, by the 4 mmol AT method (2.98 ± 0.44 W kg^{-1}), and the lowest by the LT_{loglog} method (2.17 ± 0.4 W kg^{-1}) (Table 10). The PAT values obtained in Group 4 show statistically significant differences related to the methods, excluding those derived from the 1 mmol AT and LT_{AT} methods (Table 11). In the hockey players with shorter training experience, the PAT values provided by different methods are also non-repeatable compared with Group 3.

Unlike the ice-hockey players in Group 3, the athletes in Group 4 are characterized by the high similarity of intragroup PAT values regardless of the method used (Table 12). In the group of ice-hockey players fewer than 10 years of training,

Table 8
Significance levels characterizing the differences between power values at the anaerobic threshold in the on-road cyclists yielded by different methods of lactate curve analysis (Group 3).

	Differences and significance levels			
Methods	LT_{loglog}	4 mmol AT	1 mmol AT	D-max
LT_{AT}	5.691	−1.993	0.724	4.741
p	0.001	0.05	n.s.	0.001
	LT_{loglog}	−12.424	−7.156	−4.943
	p	0.001	0.001	0.001
		4 mmol AT	7.752	11.268
		p	0.001	0.001
			1 mmol AT	4.669
			p	0.05

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15] n.s. = not significant.

Table 9
Correlations between power values at the anaerobic threshold in the on-road cyclists (Group 3) yielded by different methods of lactate curve analysis.

Correlations and significance levels				
Methods	LT_{loglog}	4 mmol AT	1 mmol AT	D-max
LT_{AT}	0.103	0.426	0.038	0.832
p	n.s	n.s.	n.s	0.001
	LT_{loglog}	0.144	−0.057	0.425
	p	n.s	n.s	n.s.
		4 mmol AT	0.887	0.577
		p	0.001	0.01
			1 mmol AT	0.467
			p	0.05

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15] n.s. = not significant.

therefore, different methods of determining the PAT provide values maintaining constant correlations, despite there being statistically significant differences.

Discussion

Comparisons of methods used to determine a lactate anaerobic threshold (LAT) concentrate on **three** issues, (1), (2) and (3). (1) The conditions under which a test is performed, as they contribute to changes in blood lactate concentration that help identify the LAT. These conditions are exercise continuity, i.e., the occurrence or nonoccurrence of breaks during exercise,[32] the place where blood is sampled from Robergas et al (1990),[53] the sizes of increments in exercise intensity,[35] and the time at the step on incremental test.[26,65] (2) A comparison of the values of the lactate and ventilatory anaerobic thresholds' parameters.[6,7,28,52,59] (3) A comparative analysis of the LAT and MLSS parameters (Heck, 1985; Atkinson and Nevill, 1998).[1,9,34] The interest in analyzing tests used to determine the LAT (Bentley et al, 2007)[3,5–8,40,47,54,58,60] has not declined in almost 30 years.[8] In training practice, the LAT is frequently replaced by the MLSS that Tegtbur et al (1993)[63] defined as "the highest exercise intensity at which blood lactate concentration does not increase beyond the initial transient during constant load exercises". This is how exercise intensity corresponding to the point of equilibrium between lactate transport into the blood and lactate removal from the blood is described in training practice.[34] A state of equilibrium between lactate generation and utilization that is characteristic of both these points (i.e., a LAT and MLSS) is one of the three significant similarities. The second similarity is lactate concentration ranging from 2.2 mmol l^{-1} to 4.4 mmol l^{-1}, which corresponds to the MLSS and the LAT. The third one is the amount by which blood lactate increases. The MLSS criterion is the same as in the 1 mmol AT method and lactate concentration growing by 1 mmol l^{-1}[12,13,41,62] or 0.2–0.5 mmol l^{-1}.[2,33] Many tests have pointed out that close relationships exist between the LAT calculated using different methods and the MLSS.[2,5,18,22,64] The relationships imply that LAT values obtained using different methods are also related. At the same time, more extensive studies investigating this problem are not available. According to existing studies, the individual anaerobic threshold[17] method and the LT_{AT}[16] method produce lower power values at the anaerobic threshold than the 4 mmol AT method. The comparisons of PAT values (yielded by the different methods of lactate curve analysis) presented do not allow us to definitely indicate a group of methods yielding similar values of exercise intensity at the LAT (Table 13).

Table 10
Power values at the anaerobic threshold (PAT) in the on-road cyclists yielded by different methods of lactate curve analysis (Group 4).

Methods of estimation AT	Power on anaerobic threshold (PAT, Watt)			
	Mean	±SD	Min	Max
LT_{AT}	2.77	0.69	1.76	4.46
LT_{loglog}	2.17	0.40	1.34	2.77
4 mmol AT	2.98	0.44	2.06	3.66
1 mmol AT	2.70	0.51	1.89	3.47
D-max	2.43	0.41	1.72	3.11

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15]

Table 11
Significance levels characterizing differences between power values at the anaerobic threshold in the on-road cyclists yielded by different methods of lactate curve analysis (Group 4).

Differences and significance levels				
Methods	LT_{loglog}	4 mmol AT	1 mmol AT	D-max
LT_{AT}	5.634	−2.525	0.724	4.741
p	0.001	0.01	n.s.	0.001
	LT_{loglog}	−12.424	−7.156	−4.943
	p	0.001	0.001	0.001
		4 mmol AT	7.752	11.268
		p	0.001	0.001
			1 mmol AT	4.033
			p	0.001

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15] n.s. = not significant.

Table 12
Correlations between power values at the anaerobic threshold in the on-road cyclists (Group 4) yielded by different methods of lactate curve analysis.

Correlations and significance levels				
Methods	LT_{loglog}	4 mmol AT	1 mmol AT	D-max
LT_{AT}	0.551	0.799	0.776	0.909
p	0.01	0.001	0.001	0.001
	LT_{loglog}	0.658	0.682	0.731
	p	0.001	0.001	0.001
		4 mmol AT	0.944	0.829
		p	0.001	0.001
			1 mmol AT	0.781
			p	0.001

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15]

Table 13
All maximum power values at the anaerobic threshold (PAT), percentages of statistically significant differences and correlations between exercise intensity values at the AT ($n = 85$).

Methods	All max PAT cases	Statistically significant differences between PAT values (% of cases)	Statistically significant correlations between PAT values (% of cases)
LT_{AT}	26	55	55
LT_{loglog}	0	80	55
4 mmol AT	40	95	65
1 mmol AT	10	70	65
D-max	8	70	45

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15]

Table 14
Regression equations for power values at the lactate anaerobic threshold yielded by the $LT_{4.0}$ method.

Methods	Regression equations
Cycling	
LT_{Visual}	$y = 0.344*x + 8.702$
$LT_{log\ log}$	$y = 1.584*x - 11.371$
$LT_{\Delta 1}$	$y = 1.064*x + 2.65$
$LT_{D\text{-}max}$	$y = 0.985*x + 1.102$
Ice-hockey	
LT_{Visual}	$y = 1.122*x - 2.578$
$LT_{log\ log}$	$y = 0.872*x + 0.381$
$LT_{\Delta 1}$	$y = 0.855*x + 1.152$
$LT_{D\text{-}max}$	$y = 0.061*x + 13.253$

Methods of estimation anaerobic threshold (AT) provided by five methods of lactate curve analysis: LT_{AT}[36,46]; LT_{loglog}[4]; 1 mmol AT[20]; 4 mmol AT[34]; and D-max.[15]

In 50% of cases, the greatest intensity was found using the 4 mmol AT method. The LT_{loglog} method did not provide the greatest value of the parameter in any of the cases. Depending on the method used, 55–90% of PAT variations are statistically significant. Only 45–65% of the exercise intensity values at the AT are correlated. With PAT values being so differentiated, it is difficult to precisely determine the intensity domains in training. Based on the analysis of the tests' findings, we can formulate regression equations for exercise intensity at the LAT determined by the LT_{Visual}, $LT_{log\ log}$, $LT_{\Delta 1}$, and $LT_{D\text{-}max}$ methods that correspond to the LT4.0 method (Table 14).

In training practice, the regression equations allow different methods of determining the LAT to be applied to assess the exercise intensity derived from the $LT_{4.0}$ method. The availability of alternative methods that can be used to find the values of exercise intensity parameters is an important element of programming training activities that reduces the risk of the exercise intensity being either underestimated or overestimated in intensity domains corresponding to metabolic thresholds.

Conclusions

The above analysis of PAT values in athletes representing disciplines involving different dominant types of energy metabolism (on-road cycling vs. ice-hockey) showed high repeatability of the parameter's values derived from different methods of lactate curve analysis. Strong correlation between PAT was found in the international-level on-road cyclists, regardless of which method was used to find the LAT. This group consisted of athletes with a high level of VO_{2max} [78.2 (±3.2) ml kg^{-1} min^{-1}]. The basic volume of their training concentrates in power ranges that different methods determine as the LATs. The athletes whose total volume of training measures includes a moderate proportion (compared with the on-road cyclist at the international level) of those aimed to increase their capacity for aerobic metabolism show lack of statistically significant correlations between PLT values obtained using different methods.

The findings offered by the statistical analysis of power values at the LAT (of the differences between the values) and from correlation analysis show that the degree to which the methods are exchangeable is determined by the metabolic effort that prevails in the training in the given discipline. The larger the share of measures improving the efficiency of aerobic energy metabolism, the greater the similarity between the parameters of training intensity provided by different methods of lactate anaerobic analysis.

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