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RELATIONSHIPS BETWEEN THE METHODS FOR ESTIMATING THE LACTATE AND VENTILATORY THRESHOLDS DURING PROLONGED EXERCISE IN ICE-HOCKEY PLAYERS

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SUMMARY

The investigation aimed to find similarities and differences between parameter values corresponding to exercise intensity at the anaerobic threshold determined using a 4MmAT method analysing the lactate curve and a method analysing ventilation changes. The VO_2, HR, PAT, and LA values at the anaerobic threshold were found to be statistically different at the level of $p \leq 0.001$. Parameter values at the anaerobic threshold as found using the 4MmAT method are lower than those provided by the V_T method, i.e. 47.13 ± 2.54 and 49.88 ± 2.37 ml×kg^{-1}×min^{-1} for VO_2AT, 161 ± 4.4 and 169 ± 5.1 bp×min^{-1} for HRAT and 3.16 ± 0.12 and 3.41 ± 0.14 W×kg^{-1} for PAT, respectively. All parameters recorded for exercise intensity at the AT level were determined to be statistically significantly related. Regardless of the method applied, power parameters at the AT level were found to be very similar, while HR values turned out to be the least similar.

Key words: anaerobic threshold, lactate threshold, ventilatory threshold, ice hockey

INTRODUCTION

Comparative analyses based on methods analysing the lactate curve do not offer a straightforward answer to the question about which of the methods are compatible. Besides, the exercise intensity values at the lactate anaerobic threshold the methods provide are not statistically significantly different. In practice, athletes are frequently tested using a method where the parameters of exercise intensity are sought using ventilatory dynamics – the ventilatory anaerobic threshold method. The accuracy of determining exercise intensity involving mainly anaerobic metabolism is crucial to selecting the right volume and intensity of training workloads (Billat, 1996). The main methods that allow finding individual exercise intensity levels corresponding to the lactate anaerobic threshold are the exponential method (LA_{AT}) described by Lundberg et al. (1986) and its modification approved by Hughson et al. (1987) for incremental exercise testing. Cheng et al. (1992) proposed a different approach to analysing the blood lactate curve (Dmax). According to those authors, the lactate anaerobic threshold is determined by the maximal distance between LA curve and the line formed by its endpoints. Stegman et al. (1981) took account of the changes in blood lactate concentration in the period of restitution. Their concept states that an individual lactate anaerobic threshold is defined by a point tangent to LA curve from recovery curve where LA is given by the value at and of incremental exercise test (GXTs), (Bentley et al., 2007, Foxdal et al., 1994). A departure from seeking an individual relationship between blood lactate concentration and exercise intensity at the lactate anaerobic threshold is the method developed by Karlson and Jacobs (1982), who took 4 mmol×l^{-1} to be the standard. Heck et al. (1985) and Mader and Heck (1986) elaborated on the concept, pointing out that there were reasons for taking a value increasing blood lactate concentration in excess of 4 mmol×l^{-1} (4MmAT) as exercise intensity at the AT level. The method has become common in training practice, as it allows finding the anaerobic threshold promptly regardless of the circumstances. An alternative to the method analysing the blood lactate curve is the Wasserman method (Wassermann, McIlroy, 1964) where the ventilatory anaerobic threshold is sought. This method assumes that the point corresponding to the anaerobic threshold is equal to exercise intensity making ventilation value grow during GXTs and change from linear to exponential. In training practice, exercise intensity is frequently found using various methods that are applied interchangeably. This approach is consistent with the assumption underlying the Wasserman method (Wassermann, McIlroy 1964), confirmed by Green H. et al. (1979), Kumanagi et al. (1982), studies, which points to rapidly growing blood lactate concentration as the cause of higher ventilation. However, many studies have failed to confirm this relationship. Hagberg et al. (1982) proved that ventilation increase was unrelated to higher blood lactate concentration. The study by Hambrechrt et al. (1994) showed that following the administration of metaprolol (an adrenolytic drug) the relationship between anaerobic lactate and anaerobic ventilatory threshold is broken. The anaerobic ventilatory threshold goes down, while the value of the lactate anaerobic threshold is stable. Physical activity depleting glycogen reserves makes the lactate anaerobic threshold take higher values, whereas the ventilatory anaerobic threshold moves down (Hughes et al., 1982, Padolin et al. 1991). The lactate anaerobic threshold is sensitive to increasing pedalling frequency (from 50 to 90 rpm) and consequently goes down. In the same circumstances, the ventilatory anaerobic threshold does not change its value (Green H. et al., 1979). Reports dealing with method compatibility in investigations involving the elite athletes are not available, though.

The presented study aimed to identify the scope of similarities and differences between parameter values at the AT level determined using the blood lactate curve method (Heck, 1991) and the method analysing ventilatory changes developed by Wasserman et al., (1973). The differences and similarities were sought in ice-hockey players. Their physical activity during the game mainly involves anaerobic metabolism and their aerobic capacity levels are a prerequisite of maintaining high efficiency during a competition season as well as the speed of restitution.

METHODS

The investigation involved a group of ice-hockey players (n = 24) at the international sport level (Polish National Team), [mean (± SD) age 25.8 ± 3.6 years, body mass 84.8 (5.1) kg, height 181.9 ± 7.7 cm, body fat 17.3 (4.4) %, training period 14–18 years]. After informing them 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 (WMDAH, 2000).

The subjects performed an incremental exercise test on the ergometer Cyclus 2 (Germany), (Bentley et al., 2007). The initial load was 1 W×kg^{-1} b.m. and increased by 0.5 W×kg^{-1} b.m every 3 minutes. Blood was sampled from the fingertip. A small incision was made using a disposable lancet (Accu-Chek Softclix , Roche, Germany). The blood samples (20 µl) were taken during the 30s periods between each 3-minute step increase in work rate stages and were immediately analysed for whole blood lactate concentration using the Biosen S-line (EKF, Gemany) (Szmatlan-Gabryś U. et al., 2009). The lactate curve was analysed using the software for calculating blood lactate endurance markers for the 4MmAT method (Newell et al., 2007). During the exercise, gas exchange parameters VO_2, VCO_2 and VE were measured breath-by-breath using the Cortex 3B Metalyser (Cortex Biophysik Germany). Exercise intensity at the ventilatory anaerobic threshold (V_T) was determined based on the VE values using the Wasserman and McIlroy method (1964).

Statistical analysis. All computations were performed with the Statistica 9.0 PL (StatSoft). The normality of distribution (the Shapiro-Wilk test) and the homogeneity of variance between the different methods were controlled for all parameters. Student paired t-tests were used to examine the difference between all four tests. Variables at the AT, determined by different methods, were compared using a Student’s paired t-test. Correlation coefficients between both variables were also calculated for each time of the day using a Pearson Product Moment Correlation Matrix. Statistical significance was accepted at $p < 0.05$.

RESULTS

Table 1 presents maximal parameter values recorded during an incremental exercise test (GXTs) in the group of ice-hockey players. The values confirm that the analysed group is representative of ice-hockey players as far as the VO_2max values are concerned (56.88 ± 3.59). According to the study by Vescovi et al. (2006), VO_2max of 53–60 ml×kg×min^{-1} is characteristic of the athletes participating in the NHL draft.

Table 1. Parameter values for aerobic endurance (VO_2max, HRmax and PCr) in the tested ice-hockey players (n = 24).

Parameter	Statistical indicator		
	Mean	SD	V [%]
VO_2max [ml×kg×min^{-1}]	56.88	3.59	6.31
HRmax [ud×min^{-1}]	187	4.40	2.35
PCr [W×kg^{-1}]	4.08	0.29	7.11

Table 2 presents parameter values at the AT level determined in the group of ice-hockey players using the 4MmAT and V_T methods. The statistical significance of the differences is shown in table 3. The VO_2, HR, PAT and LA values at the anaerobic threshold were found to be statistically significantly different – $p \leq 0.001$. The parameter values corresponding to exercise intensity at the anaerobic threshold as recorded by the 4MmAT method are lower than those obtained using the V_T method, i.e. 47.13 ± 2.54 and 49.88 ± 2.37 ml×kg^{-1}×min^{-1} for VO_2AT, 161 ± 4.4 and 169 ± 5.1 bp×min^{-1} for HRAT and 3.16 ± 0.12 and 3.41 ± 0.14 W×kg^{-1} for PAT, respectively. The parameter values at the anaerobic threshold given as the percentages of the maximal values as well as blood lactate concentrations are also higher in the V_T method. The differences between the values range between 4 and 9% (table 3).

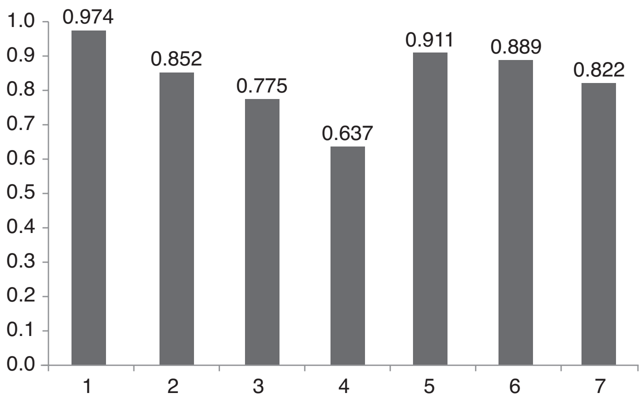
Table 2. Parameter values of aerobic endurance as provided by the 4MmAT and V_T methods during an incremental exercise test.

Method	Parameter	Statistical indicator		
		Mean	SD	V [%]
4 MmAT	VO_2AT [ml×kg^{-1}×min^{-1}]	47.18	2.54	5.38
	VO_2maxAT [%]	81.73	2.89	3.54
	HRAT[bp×min^{-1}]	161.2	4.4	2.73
	HRmaxAT [%]	81.58	3.7	4.55
	PAT [W×kg^{-1}]	3.1	0.12	3.87
	PCrAT [%]	73.69	4.34	5.89
	LAAT [mmol×l^{-1}]	4.02	0.07	1.74
V_T	VO_2AT [ml×kg^{-1}×min^{-1}]	49.88	2.77	5.55
	VO_2maxAT [%]	86.85	3.14	3.62
	HRAT[bp×min^{-1}]	169.7	5.1	4.88
	HRmaxAT [%]	89.19	3.25	3.64
	PAT [W×kg^{-1}]	3.41	0.14	4.11
	PCrAT [%]	79.79	3.04	3.81
	LAAT [mmol×l^{-1}]	4.18	0.13	3.11

Table 3. Differences between parameter values for aerobic endurance as provided by the 4MmAT and VT methods during an incremental exercise test.

Parameter	Method	Mean	Difference		Significance levels of differences for t-Student	
			actual values	%	t	P
VO_2AT [ml×kg×min^{-1}]	1	47.18				
	2	49.88	2.7	5.41	15.879	0.001
VO_2maxAT [%]	1	81.73				
	2	86.85	5.12	6.26	15.691	0.001
HRAT [ud×min^{-1}]	1	161.2				
	2	169.7	8.5	5	12.729	0.001
HRmaxAT [%]	1	81.58				
	2	89.19	7.61	9.32	12.968	0.001
PAT [W×kg^{-1}]	1	3.1				
	2	3.41	0.31	11	8.581	0.001
PCrAT [%]	1	73.69				
	2	79.79	6.1	8.28	9.12	0.001
LAAT [mmol×l^{-1}]	1	4.02				
	2	4.18	0.16	3.98	5.895	0.001

Graph 1 illustrates the relationships between the equivalent parameters' values recorded at the anaerobic threshold using the VT and 4MmAT methods. The strongest statistically significant relationship was found for oxygen consumption at the anaerobic threshold (VO_2AT, $r = 0.974$, $p \leq 0.001$), power at the anaerobic threshold (PAT, $r = 0.911$, $p \leq 0.001$) and power as a percentage of critical power (PCrAT [%], $r = 0.889$, $p \leq 0.001$). The weakest statistical significance of the relationships was determined for two values at the anaerobic threshold, i.e. the heart rate percentage (HRAT, $r = 0.775$, $p \leq 0.001$) and the heart rate as the percentage of the maximal value (HRmaxAT, $r = 0.637$, $p \leq 0.001$).



Graph 1. Relationships between parameter values recorded at the AT level using the 4 mmol method and the ventilation method in the group of the ice-hockey players (n = 16). Parameters: 1 – VO_2AT; 2 –VO_2maxAT [%]; 3 – HRAT; 4 – HRmaxAT [%]; 5 – PAT; 6 – PCrAT [%]; 7 – LAAT.

DISCUSSION OF RESULTS

The presented comparative analysis of aerobic endurance parameter values generated by the methods based on blood lactate changes and ventilation changes during an incremental exercise test showed that the differences were considerable and that the relationships between them were statistically significant. The training effort parameters as determined using the two methods are higher for the method analysing ventilation changes. The earlier studies indicated a reverse relationship. Linking the occurrence of a ventilation threshold with increasing blood lactate concentration, Wassermann and McIlroy (1964) pointed to the similarity of exercise intensity levels at which the two thresholds appear. On the other hand, Pilis et al. (1996) highlighted the considerable differences between exercise intensity values at the aerobic threshold determined using methods based on ventilation and lactate kinetics. The investigations by Hagberg et al. (1982) demonstrated that building up blood lactate concentration does not have to increase ventilation. Observations of changes in both thresholds (lactate and ventilatory) induced by a 3-week training period showed that while the lactate threshold changed by 14% the ventilatory threshold remained the same (Poole, Gaesser, 1985, Gaesser & Poole, 1986). Neary et al. (1985) also proved that parameter values at the lactate and ventilatory anaerobic thresholds do not always have to correspond to each other. Edwards et al. (2003) found that oxygen consumption values at the lactate and ventilatory anaerobic thresholds changed similarly in professional soccer players. Using the VT approach, Yamamoto et al. (1991) proved that the MLSS (maximal lactate steady state) was underestimated, which indicates that the lactate and ventilatory anaerobic thresholds are not closely correlated. The van Schuylenbergh et al. (2004) investigation into a group of cyclists demonstrated that the only statistically significant relationship ($r = 0.77$) was that between HR values at the ventilatory anaerobic threshold and at the MLSS level. In their comparative studies, Mikulic et al. (2009) found that the ventilatory anaerobic threshold and the heart rate deflection point ($r = 0.79$–0.96; $p < 0.001$) are closely correlated in the rowers, identifying also a small, statistically significant difference between HR values (174.5 vs. 172.8 beats×min^{-1}; $p \leq 0.003$). These HR values at the AT level correspond to those recorded in the group of the examined ice-hockey players. Bodner et al. (2002) carried out a comparative study of parameter values recorded at the ventilatory anaerobic threshold (VT) and the heart rate deflection point (HRDP) in a group of cyclists, finding no statistically significant differences between HR values (171.7 ± 9.6 b×min^{-1} and 169.8 ± 9.9 b×min^{-1}) and between VO_2 values (53.6 ± 4.2 ml×kg×min^{-1} and 52.2 ± 4.8 ml×kg×min^{-1}) as measured at the HRDP and VT levels, respectively. However, statistically significant differences ($p < 0.01$) were determined between power values for the HRDP (318.7 ± 30.7 W) and the VT (334.8 ± 36.7 W). Besides, correlation coefficients showing the relations between HR ($r = 0.92$, $p < 0.001$), VO_2 ($r = 0.72$, $p < 0.001$) and power ($r = 0.77$, $p < 0.001$) calculated using the two methods were found to be similar to those recorded in the group of ice-hockey players. Comparing parameter values at the ventilatory threshold (VT), the lactate anaerobic threshold (LA_{AT}) and HRDP, Karapetian et al. (2008) found VO_2 not to be different (0.12 ± 0.2 and 0.06 ± 0.3 l×min^{-1}, respectively). Significant differences within HR values for the HRDP and LAAT were not found, either ($p > 0.05$); however, HR was found to be significantly different between VT and LA_{AT}

($p < 0.05$). The parameter correlation coefficient ranged between 0.82 and 0.85 ($p < 0.001$). This range corresponds to the correlation found between parameter values recorded using the VT and 4MmAT methods in the examined ice-hockey players. A comparative analysis of parameter values at the VT and HRDP carried out by Debray and Dey (2007) in the group of young boys aged 12–13 years showed that the VO_2 values (1.46 and 1.45 $l \times min^{-1}$, respectively) accounted for 84% and 83% of VO_2max and that the correlation between them was statistically significant ($r = 0.94$, $p < 0.01$). Cottin et al. (2006) and Grazzi et al. (2008) confirmed that HR values found using the VT and HRDP methods are correlated statistically significantly. Plato et al. (2008) performed a comparative analysis of parameter values at the lactate (D-max) and ventilatory thresholds in a group of recreational cyclists. The correlation coefficient between HR values was statistically significant 0.67 ($p < 0.05$). The conducted research and the analyses of other authors' data do not allow treating the differences as constant and establishing their actual values for oxygen endurance parameters calculated using different methods. This character of the differences may arise from the athlete's specialisation and competence, the predominating type of energy involved in exercise, as well as other factors related to the athlete's energy metabolism during exercise, including the exercise test characteristics (Edwards et al., 2003). When a comparative evaluation of the parameters is being performed, the nature of the effort also needs to be taken into account. The Koepp, Janot study (2008) has found statistically significant differences between VO_2max, VCO_2 and maximal RER at $p < 0.05$ in hockey players exercising on a running treadmill and a skating treadmill, respectively. However, the Martinez et al. study (1994) has not shown statistically significant differences between the physiological parameters (VO_2max, HRmax) and the biochemical parameters (LA) recorded during exercises of comparable intensity performed on a cycloergometer and a skating treadmill, the latter exercise greatly resembling skating regarding the character of the motion. The above results confirm that it is correct to use a cycloergometer instead of a treadmill in procedures for determining the physiological indicators of hockey player preparedness.

CONCLUSION

All parameters of exercise intensity at the AT level were found to be statistically significantly correlated. The level of significance varies depending on the methods being compared. Regardless of the method applied, a strong relationship between PAT values was identified. Compared with the other parameters, the relationships were found to be statistically significantly the weakest for HR values at the AT level. This information is important for training workload programming, as the workloads used are frequently related not to power or speed but to HR values, but also in the context of the earlier studies where the largest similarity was found for HR levels determined by the VT and other methods.

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Shortcuts applied in the work

VO_2AT [ml×kg^{-1}×min^{-1}]	maximal oxygen uptake
VO_2maxAT [%]	maximal oxygen uptake on anaerobic threshold
HRAT[bp×min^{-1}]	heart rate on anaerobic threshold
HRmaxAT [%]	maximal heart rate on anaerobic threshold
PAT [W×kg^{-1}]	power on anaerobic threshold
PCrAT [%]	critical power
LAAT [mmol×l^{-1}]	exercise intensity levels corresponding to the lactate anaerobic threshold

VZTAHY MEZI METODAMI URČOVÁNÍ PRAHOVÝCH HODNOT LAKTÁTU A VENTILACE V PRŮBĚHU DÉLETRVAJÍCÍCH CVIČENÍ HRÁČŮ LEDNÍHO HOKEJE

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SOUHRN

Cílem šetření bylo nalézt podobnosti a rozdíly hodnot ukazatelů odpovídajících intenzitě cvičení na úrovni anaerobního prahu stanovené pomocí 4MmAT metody analyzující laktátovou křivku a metody analyzující změny ventilace. Statisticky významné rozdíly (na úrovni $p \leq 0.001$) byly nalezeny u hodnot VO_2, SF, výkonu a laktátu na úrovni anaerobního prahu. Hodnoty zjištěné metodou 4MmAT byly nižší než hodnoty zjištěné měřením změn ventilace, konkrétně 47.13 ± 2.54 a 49.88 ± 2.37 ml×kg^{-1}×min^{-1} u VO_2, 161 ± 4.4 a

169 ± 5.1 bp×min^{-1} u SF a 3.16 ± 0.12 a 3.41 ± 0.14 W×kg^{-1} u výkonu. Souvislosti mezi všemi parametry cvičení na úrovni anaerobního prahu byly shledány statisticky významnými. Zjištěné parametry výkonu na úrovni anaerobního prahu byly podobné bez ohledu na použité metody, přičemž hodnoty SF byly velmi podobné.

Klíčová slova: anaerobní práh, laktátový práh, ventilační práh, lední hokej

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