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PROBLEMS IN DETERMINATION OF THE VENTILATORY THRESHOLD BASED ON THE RESPIRATORY EXCHANGE RATIO IN HIGH-LEVEL ATHLETES

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Stanislav Tzvetkov[1], Peter Bonov[2], Daniela Dasheva[2]

[1]Department of Sports Medicine, National Sports Academy, St. grad, 1710 Sofia, Bulgaria,
[2]National Sports Academy, St. grad, 1710 Sofia, Bulgaria,
E-mail: st.tzvetkov@gmail.com, bonov@nsa.bg, dani_dash@yahoo.com

Abstract. *As an alternative to the invasive lactate anaerobic threshold determination, a number of methods for detection of the ventilatory threshold (VT) are applied – using the respiratory exchange ratio ($VT_{RER=1.0}$), the breakpoint of the nonlinear increase of the ventilatory equivalent for oxygen (VT_{EqO2}) and the Vco_2 versus Vo_2 curve ($VT_{V\text{-}slope}$). Some researchers identify a respiratory compensation point (RCP); others question the accuracy of the VT_{RER} method. We aimed to compare the results for $VT_{RER=1.0}$, VT_{EqO2}, $VT_{V\text{-}slope}$ and RCP in 18 high-level male athletes who are involved in aerobic sports. In the One-Way ANOVA test a significant difference was demonstrated between the corresponding values of VO_2 and WC ($F = 7.95$ and $F = 14.53$; $p < 0.05$) in the pairs $VT_{V\text{-}slope}$ - $VT_{RER=1.0}$, $VT_{V\text{-}slope}$ - RCP, VT_{EqO2} - $VT_{RER=1.0}$ and VT_{EqO2} - RCP. The multiple pair-wise comparison analysis for VO_2 and WC revealed a lack of statistically acceptable interchangeability of $VT_{RER=1.0}$ with $VT_{V\text{-}slope}$ and VT_{EqO2}.*

Key words: *respiratory exchange gases, ventilatory threshold, comparative analysis*

INTRODUCTION

The application of the concept for the aerobic-anaerobic metabolic transition for the control and planning of workloads in sport is a fundamental scientific approach in the programming of the training process. An important criterion, which determines the ability for continuous exercise is the balance between energy production and utilization in the working muscles. The reciprocal coordination of these two processes is limited by the individual characteristics of the cardio-vascular system and muscle metabolism, due to which a "critical threshold" – anaerobic threshold (AT) - is observed during a physical ef-

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fort (Wasserman & McIlroy, 1964). Exercising at intensity above AT impairs the balance of the aerobic-anaerobic processes with lactate accumulation in the muscles, resulting in a sharp reduction of the functional capacity (FC) (Wasserman et al., 1973). The invasive character of the procedures for AT determination by analyzing the lactate levels in arterial blood has motivated a number of researchers to improve non-invasive methods, based on the analysis of the respiratory exchange and determination of a ventilatory threshold (VT). The methods used for VT determination include: analysis of the respiratory exchange ratio (RER) at the level of RER = 1.0 ($VT_{RER=1.0}$), the breakpoint of nonlinear increase of the ventilatory equivalent of oxygen (VT_{EqO2}) and the V_{CO2} versus V_{O2} curve ($VT_{V\text{-}slope}$) (Yeh et al., 1983; Solberg et al., 2005). The studies of Caiozzo, Davis, & Ellis (1982) and Beaver, Wasserman, & Whipp (1986) on VT_{EqO2} and $VT_{V\text{-}slope}$ question VT_{RER} as an effective method for VT determination. Some researchers have identified a second breakpoint of nonlinear increase of pulmonary ventilation during incremental exercise tests – a respiratory compensation point (RCP) (McLellan, 1985). According to them, RCP corresponds to a more significant increase in pulmonary ventilation due to exhaustion of the compensatory abilities of the buffer systems and a sharp increase in the CO_2 body accumulation (Meyer et al., 2004). A common characteristic of the described methods for VT determination is their causal relationship to the specific dynamics of the respiratory exchange. Sometimes during the exercise testing of subjects with high FC, objective maximum of the effort is reached at low RER_{max} (0.99 ÷ 1.01). The role of the various regulatory mechanisms in this adaptive process has not been yet fully explained; however, this aspect in the dynamics of RER significantly limits the alternatives for accurate $VT_{RER=1.0}$ determination.

The aim of the present study was to compare the results for $VT_{RER=1.0}$, VT_{EqO2}, $VT_{V\text{-}slope}$ and RCP, determined by the discussed methods. Data were obtained during maximal exercise tests of high-level athletes who participate in sports with a predominantly aerobic type of energy supply.

METHODS

Subjects

The subjects of the study were 18 high-level national male athletes, aged 21.06 (± 2.46), all from the national teams of predominantly aerobic sports – athletics (middle distance runners – 1500, 2000 and 3000 m), orienteering and biathlon. All of the subjects were healthy, injury-free and non-smokers. Before participating in the study, each subject was familiarized with the experimental procedure and informed of the risks associated with the protocol. All of the subjects gave their written voluntary informed consent. Their physical characteristics are summarized in Table 1.

Table 1. Physical characteristics of the subjects (n = 18)

Parameters	Mean	± SD
Age (years)	21.06	± 2.46
Height (cm)	179.58	± 4.97
Weight (kg)	69.22	± 6.85
BMI	21.67	± 1.47

Experimental procedure

To avoid external influence on the tested functional parameters, 2 days prior to the testing all of the athletes carried out their training at low intensity. After a 5-minute warm-up at low speed, which allowed the subjects to adapt to exercise, they performed a maximal incremental test on a treadmill (Quasar - 4.0, Med; HP Cosmos, Germany). The exercise stepwise model of Iliev (Iliev, 1974) was applied, with an initial speed of 6 kmh^{-1}, increased by 1.2 km h^{-1} every 90 sec, with constant elevation of 2.5 %, until objective voluntary exhaustion was achieved. The following criteria were used to verify maximal exertion: a plateau in oxygen consumption (VO_2) dynamics; RER_{max} > 1.10; maximal heart rate ($HR_{max\ (real)}$) close to the maximal heart rate predicted based on the subject's age and physical inability to continue the test (Wasserman et al., 2005; Robergs, 2001; Duncan et al., 1997; Tanaka et al., 2001).

Gas exchange measurements and Ventilatory threshold determination

Gas exchange was measured throughout the test using a metabolic system Oxycon Pro (Erich Jaeger GmBH & Co Wuerzburg, Germany). Before each test, the gas-analyzers were calibrated using ambient air (20.9 % O_2 and 0.04 % CO_2) and calibration gas (0.00 % O_2 and 4.83 % CO_2). The calibration of the turbine flow-meter of the volume sensor was performed with a standard 3-L syringe. Gas-exchange was registered continuously during each test using the breath-by-breath method (Gaskill & al., 2001). VT_{RER} was defined at the level of RER = 1.0 ($VT_{RER=1.0}$) (Solberg & al., 2005; Myers & Ashley, 1997). For some athletes, the VT_{RERBP} was determined additionally – a detection of a "breakpoint" in the RER dynamic using an abrupt systematic increase (Wasserman & al., 1973; Carey & al., 2005) and $VT_{RER=0.95}$ – VT_{RER} calculated at the level of RER = 0.95 (Amann & al., 2004). VT_{EqO2} (Caiozzo & al., 1982), $VT_{V\text{-}slope}$ (Beaver & al., 1986) and RCP (McLellan, 1985; Meyer & al., 2004; Reinhard & al., 1979) were determined with a linear regression analysis using a specialized mathematic software ("MATLAB" – 6.1) (Diniz & Brochi, 2005; Koul & Qian, 2002). Based on the abovementioned criteria, two experienced researchers independently assessed the ventilatory thresholds. When they could not determine a threshold, the subject's threshold was excluded from the processing. For all of the methods the corresponding values of work capacity (WC) and VO_2 at VTs and RCP were statistically analyzed.

Hematological measurements

Before the exercise test, a venous blood sample was taken from a peripheral arm vein and the following hematological parameters were analyzed (RAL, Spain): hemoglobin (HB); red blood cell count (RBC); hematocrit (HTC); mean cell volume (MCV); mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC). The sample was taken before the 5-minute warm-up. The accuracy of the RAL – analyzing device was previously validated. For all of the subjects the main hematological characteristics were within the upper limits of the normal reference value range (Table 2).

Table 2. Hematological characteristics of the subjects and the laboratory reference values

Parameters	Mean	± SD	Reference values
HB (g l^{-1})	149.56	8.07	120 – 174
RBC (10E 12/l)	5.48	0.31	4.00 – 5.50
HTC (%)	49.04	2.67	36.0 – 52.0
MCV (fl)	89.56	2.61	76.0 – 96.0
MCH (g l^{-1})	28.29	1.01	27.0 – 32.0
MCHC (g l^{-1})	305.13	4.35	300 – 350

The obtained values for WC and VO_2 at VT_{EqO2}, $VT_{V\text{-}slope}$, $VT_{RER=1.0}$ and RCP were statistically processed with a one-way ANOVA - test and pair-wise comparison analysis, preceded by a distribution normality check of the respective samples with the Kolmogorov-Smirnov and Shapiro-Wilk tests (Stuart & al., 1999). The student's T criterion was used for evaluation of the statistical results with a standard level of significance ($p < 0.05$) /SPSS 14/.

RESULTS

Maximal functional characteristics and validity of the maximal exercise test

All of the subjects involved in the study had high values of the maximal functional parameters (Table 3). At the end of the test, the mean RER_{max} was 1.17 (± 0.08). The measured $HR_{max\ (real)}$ was not significantly different from the theoretically estimated HR_{max} ($HR_{max(theory)} = 208 - [0.7 \times age]$). All of the subjects fulfilled the criteria for objectivity of the maximal exertion; therefore, maximal oxygen consumption (VO_{2max}) was reached and the VTs were exceeded during the test.

Table 3. Exercise performance the during maximal incremental exercise test of subjects

Parameters	Mean	± SD
Maximal VO_2 (ml min^{-1})	4794.32	479.18
Maximal VO_2 (ml kg^{-1} min^{-1})	67.82	3.54
Maximal heart rate (beats min^{-1})	194.17	4.69
Maximal ventilation (l min^{-1})	167.89	12.68
Maximal work capacity (MET)	18.47	1.26
Maximal respiratory exchange ratio	1.17	0.08

Ventilatory threshold and RCP assessment

Despite the objective maximal effort and the high VO_{2max} values = 4531.76 (± 258.18) ml min^{-1}, WC_{max} = 18.61 (± 1.41) MET and $HR_{max\ (real)}$ = 195 (± 3.17) beats min^{-1}, in 3 of the tested subjects the RER_{max} was low (0.99 ÷ 1.01), which did not allow a correct determination of the $VT_{RER=1.0}$. These subjects (exception subjects (ES)) were excluded from the statistical analysis. The results for VTs and RCP of the other 15 athletes were analyzed for the reliability of the null hypothesis on the statistically significant difference between the values of WC and VO_2, corresponding to $VT_{RER=1.0}$, VT_{EqO2}, $VT_{V\text{-}slope}$ and RCP. In the One-Way ANOVA test a significant difference was demonstrated between the values of VO_2 and WC (F = 7.95 and F = 14.53; p < 0.05) in the pairs $VT_{V\text{-slope}}$ - $VT_{RER=1.0}$, $VT_{V\text{-slope}}$ - RCP, VT_{EqO2} - $VT_{RER=1.0}$ and VT_{EqO2} - RCP. The multiple pair-wise comparative analysis for VO_2 and WC revealed a strong correlation between $VT_{V\text{-slope}}$ to VT_{EqO2} (r = 0.867, t = 1.57, p = 0.95; r = 0.799, t =1.81, p = 1.08) and $VT_{RER=1.0}$ to RCP (r = 0.955, t = 1.41, p = 1.03; r = 0.887, t =1.14, p = 0.62) (Table 4).

Table 4. Means, standard deviations, correlation coefficients (r), t – values and p - values from multiple pair-wise comparison analysis for VO_2 (ml min^{-1}) and WC (MET) corresponding to the determined VT-s and RCP (n = 15)

Parameters		Mean	± SD	r	t	p
$VT_{V\text{-slope}}$ to VT_{EqO2}	VO_2	3447.27 3684.00	± 340.32 ± 384.33	0.867	1.57	0.95
	WC	14.32 15.11	± 1.57 ± 1.06	0.799	1.81	0.08
$VT_{V\text{-slope}}$ to $VT_{RER=1.0}$	VO_2	3447. 27 4082.40	± 340.32 ± 543.11	0.653	4.58	< 0.05
	WC	14.32 16.80	± 1.57 ± 1.33	0.435	6.24	< 0.05
VT_{EqO2} to $VT_{RER=1.0}$	VO_2	3684.00 4082.40	± 384.33 ± 543.11	0.682	5.57	< 0.05
	WC	15.11 16.80	± 1.06 ± 1.33	0.563	6.47	< 0.05
$VT_{V\text{-slope}}$ to RCP	VO_2	3447. 27 4141.53	± 340.32 ± 517.53	0.638	6.48	< 0.05
	WC	14.32 17.06	± 1.57 ± 1.42	0.413	7.69	< 0.05
VT_{EqO2} to RCP	VO_2	3684.00 4141.53	± 384.33 ± 517.53	0.646	4.86	< 0.05
	WC	15.11 17.06	± 1.06 ± 1.42	0.601	6.65	< 0.05
$VT_{RER=1.0}$ to RCP	VO_2	4082.40 4141.53	± 543.11 ± 517.53	0.955	1.41	1.03
	WC	16.80 17.06	± 1.33 ± 1.42	0.887	1.14	0.62

Exception subjects: In one of the ES $VT_{RER=1.0}$ could not be determined; in the others ES the $VT_{RER=1.0}$ - values were very high, not practically applicable. The impossibility for the correct determination of $VT_{RER=1.0}$ has motivated us to analyze alternative approaches for VT_{RER} determination for these athletes, using the VT_{RERBP} and $VT_{RER=0.95}$ – methods (Fig. 1). The comparison of the WC and VO_2 values at VT_{RERBP} (WC_{RERBP}, VO_{2RERBP}), $VT_{RER=0.95}$ ($WC_{RER=0.95}$, $VO_{2RER=0.95}$) and $VT_{RER=1.0}$ ($WC_{RER=1.0}$, $VO_{2RER=1.0}$) with WC and VO_2 at VT_{EqO2}, $VT_{V\text{-slope}}$ and RCP revealed significant heterogeneity and visual discrepancy for $WC_{RER=0.95}$, $VO_{2RER=0.95}$, $WC_{RER=1.0}$ and $VO_{2RER=1.0}$ (Table 5). As demonstrated in the table, the values were similar only for WC_{RERBP} and VO_{2RERBP} to WC and VO_2 at VT_{EqO2} and $VT_{V\text{-slope}}$. Meanwhile $WC_{RER=1.0}$ and $VO_{2RER=1.0}$ values were too high, close to WC and VO_2 at RCP and the maximum of the physical effort.

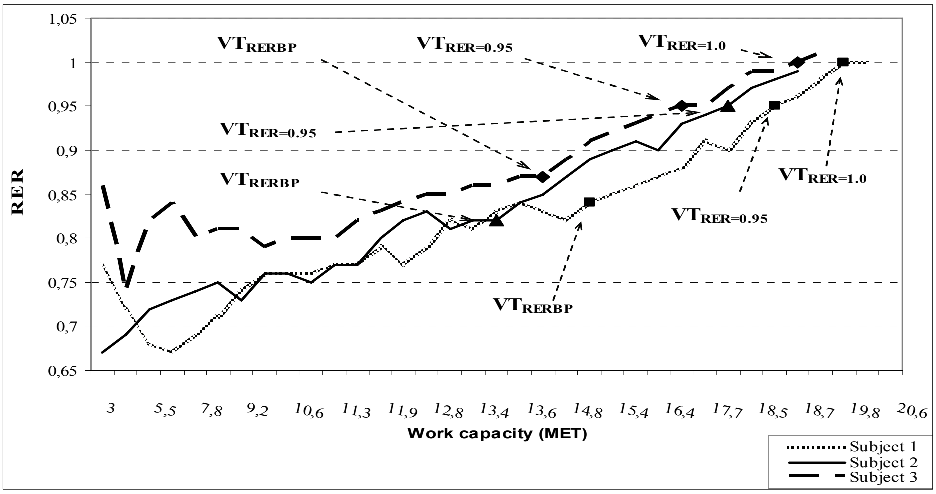

Fig. 1. The results obtained for VT_{RER}, determined with the VT_{RERBP} – method, VT_{RER} at RER = 0.95 – method ($VT_{RER=0.95}$) and VT_{RER} at RER = 1.0 – method ($VT_{RER=1.0}$) for the exception subjects (n = 3)

Table 5. VO_2 values (ml min^{-1}) and WC values (MET) corresponding to the determined VT-s and RCP of the exception subjects (n = 3)

Subjects	Parameters						
		VT_{RERBP}	$VT_{RER=0.95}$	$VT_{RER=1.0}$	$VT_{V\text{-}slope}$	VT_{EqO2}	RCP
Subject 1	VO_2	3287.0	3851.0	4314.0	2749.0	3535.0	4054.0
	WC	15.2	18.7	19.5	10.8	15.4	19.1
Subject 2	VO_2	3659.0	4545.0	-	3440.0	3855.0	4685.0
	WC	13.4	17.8	-	13.2	13.5	18.0
Subject 3	VO_2	3623.0	4186.0	4464.0	3486.0	3883.0	4336.0
	WC	14.1	16.9	18.6	13.4	14.5	17.7

DISCUSSION

The registered hematological parameters of the subjects were within the upper limits of the normal range, thus supposing an effective oxygen-carrying capacity of the arterialized blood; these parameters were not expected to limit the FC. The comparative analysis of the mean values for WC_{max} and VO_{2max} of the subjects participating in the study (Table 3) with published data on elite athletes from the same sports (middle distance running, orienteering and biathlon) allowed us to qualify them as high-level athletes with a high functional capacity (Svedenhag & Sjödin, 1985; Creagh & Reilly, 1997; Klusiewicz et al., 2004). The results from the One-Way ANOVA test between WC and VO_2 corresponding to $VT_{RER=1.0}$, VT_{EqO2}, $VT_{V\text{-}slope}$ and RCP demonstrated a lack of statistically acceptable interchangeability between $VT_{RER=1.0}$ compared to $VT_{V\text{-}slope}$ (for WC - r = 0.435, t = 6.24, $p < 0.05$; for VO_2 - r = 0.653, t = 4.58, $p < 0.05$) and to VT_{EqO2} (for WC - r = 0.563, t = 6.47, $p < 0.05$; for VO_2 - r = 0.682, t = 5.57, $p < 0.05$) (Table 4). This fact is in concordance with the opinion of Caiozzo, Davis, & Ellis (1982) and Beaver, Wasserman, & Whipp (1986) on the questionable efficacy of VT_{RER} method for VT determination. $WC_{RER=1.0}$ and $VO_{2RER=1.0}$ ($WC_{RER=1.0}$ = 16.80 (± 1.33); $VO_{2RER=1.0}$ = 4082.40 (± 543.11)) were significantly higher than those corresponding to $VT_{V\text{-}slope}$ and VT_{EqO2}, approaching the RCP values (WC_{RCP} = 17.06 (± 1.42); VO_{2RCP} = 4141.53 (± 517.53)) with a very high correlation coefficient (for WC - r = 0.887, t = 1.14, p = 0.62; for VO_2 - r = 0.955, t=1.41, p = 1.03). Based on this result we can assume that the determined $VT_{RER=1.0}$ corresponds to a significantly higher degree to RCP than to VT_{EqO2} and $VT_{V\text{-}slope}$.

This, in certain cases, does not allow the correct detection of a practically applicable $VT_{RER=1.0}$ (as observed in the 3 exception subjects), and requires the additional application of other methods for determination of VT_{RER}, such as VT_{RERBP} and $VT_{RER=0.95}$. The VT_{RERBP} – method is based on determination of a "breakpoint" in the RER dynamic. The work rate during an exercise test, during which the RER demonstrates an abrupt systematic increase, was used by Wasserman et al., 1973 as an alternative method for VT_{RER} detection. Since this method is not significantly dependent on the adaptive processes, which determine RER_{max} values ≤ 1.0, it may be expected that it will give more precise information on VT. Despite the wide-spread application of the $VT_{RER=1.0}$ – method (Yeh et al., 1983; Solberg et al., 2005), some researchers are of the opinion that VT corresponds to the level of RER = 0.95 (Amann et al., 2004). The comparative analysis of the alternative VT_{RERBP} and $VT_{RER=0.95}$ – methods with $VT_{RER=1.0}$ revealed a significant difference among the three VTs (Fig. 1). The values for WC_{RERBP}, VO_{2RERBP}, $WC_{RER=0.95}$, $VO_{2RER=0.95}$, $WC_{RER=1.0}$ and $VO_{2RER=1.0}$ demonstrate that only WC_{RERBP} and VO_{2RERBP} have acceptable correspondence with WC and VO_2 at VT_{EqO2} and $VT_{V\text{-}slope}$ (Table 5). The presented data yet again underline the fact that in high-level athletes significantly higher values of $VT_{RER=1.0}$ compared to VT_{EqO2} and $VT_{V\text{-}slope}$ are observed, which are very close to the RCP-values. Probably there are multiple factors of various characters, determining the problem with the application of $VT_{RER=1.0}$ in high-level athletes; however, it is logical to assume that the optimal adaptation to workload and the high FC of the tested subjects are of significance. The RER is determined by dividing the volume of the expired CO_2 by the inspired O_2 (Wasserman et al., 2005); therefore, it directly depends on the respiratory parameters. It is acknowledged that the adaptive regulation of the respiratory function during exercising is realized alongside with the humoral one, with the active participation of nervous regulatory mechanisms (Dejours et al., 1964).

It is natural to assume that the well developed adaptive capabilities in subjects with high FC affect the regulation of the respiratory function and the tested respiratory parameters. This claim is supported by Deruelle et al., (2006), according to whom the specific experience of elite athletes ensures significant advantage in the voluntary control of the respiratory function compared to subjects with low FC. In concordance with this finding, the subjects in our study, having been tested repeatedly over the years, have possibly developed adaptive components which influence the RER dynamics. It should be also stressed that RER-values are affected by a number of environmental factors such as energy balance, the size of the glycogen stores, the amount of adipose tissue, and the fat/carbohydrate mix in one's regular diet (Schutz, 1995). The physiological interpretation of RER is in the percentage of energy provided from carbohydrates versus fat oxidation. Generally, a low RER (0.7 ÷ 0.8) indicates high fat oxidation levels, while a RER of 1.0 or greater indicates that carbohydrates are the only fuel oxidized (Peronnet & Massicotte, 1991). It has also been established that RER depends on physical activity (Coggan et al.,

2000) and it might also be affected by genetically determined characteristics such as muscle fiber type (Kempen et al., 1998).

In conclusion, we can summarize that the application of $VT_{RER=1.0}$ in high-level athletes with high FC is associated with a risk of obtaining unrealistic results, which would compromise their practical value. Probably adaptive processes, which influence the respiratory regulation and the tested respiratory parameters may affect the detection of $VT_{RER=1.0}$. The multiple factors, which have an effect on the dynamics of the RER – values during exercise and the contradictory opinions on the use of the VT_{RER} – method may compromise the determination of $VT_{RER=1.0}$. In some high-level athletes with $RER_{max} \leq 1.0$, $VT_{RER=1.0}$ cannot be used, which requires further investigations on the criteria for VT_{RER} determination.

REFERENCES

1. Amann, M.,Subudhi, A., Walker, J., Eisenman, P., Shultz, B., & Foster C. (2004). An evaluation of the predictive validity and reliability of ventilatory threshold. *Medicine & Science in Sports & Exercise*, 36, 10, 1716-1722.
2. Beaver, W., Wasserman, K., & Whipp, B. (1986). A new method for detecting anaerobic threshold by gas exchange. *Journal of Applied Physiology*, 60, 2020-2027.
3. Caiozzo, V., Davis, J., & Ellis, J. (1982). A comparison of gas exchange indices used to detect the anaerobic threshold. *Journal of Applied Physiology*, 53, 1184-1189.
4. Carey, D., Schwarz, L., Pliego, G., & Raymond, R. (2005). Respiratory rate is a valid and reliable marker of the anaerobic threshold: Implications for measuring change in fitness. *Journal of Sports Science and Medicine*, 4, 482-488.
5. Coggan, A., Raguso, C., Gastalkelli, A., Sidossis, L., & Yeckel, C. (2000). Fat metabolism during high-intensity exercise in indurance-trained and untrained men. *Metabolism: Clinical and Experimental*, 49, 122-128.
6. Creagh, U., & Reilly, T. (1997). Physiological and biomechanical aspects of orienteering. *Sports Medicine*, 24, 409-418.
7. Dejours, P., Fenn, O., & Rahn, H. (1964). *Control of respiration in muscular exercise. Handbook of Physiology*. Washington: American Physiological Society.
8. Deruelle, F., Nourry, C., Mucci, P., Bart, F., Grosbois, J., Lensel, G., & Fabre C. (2006). Breathing strategy in master athletes and untrained elderly subjects according to the incremental protocol. *Applied Physiology, Nutrition, and Metabolism*, 31, 202-210.
9. Diniz, C., & Brochi, L. (2005). Robustness of two-phase regression test. *Statistical Journal*, 3 (1), 1-18.
10. Duncan, G., Howley, E., & Johnson, B. (1997). Applicability of [spacing dot above] VO2max criteria: discontinuous versus continuous protocols. *Medicine & Science in Sports & Exercise*, 29 (2), 273-278.
11. Gaskill, S., Ruby, B., Walker, A., Sanchez, O., Serfass, R., & Leon, A. (2001). Validity and reliability of combining three methods to determine ventilatory threshold. *Medicine & Science in Sports & Exercise*, 33 (11), 1841–1848.
12. Iliev, I. (1974). *A method for complex testing of high-class athletes*. BSFS, Sofia. (in Bulgarian).
13. Kempen, K., Saris, W., Kuipers, H., Glatz, J., & Van der Vusse, G. (1998). Skeletal muscle metabolic characteristics before and after energy restriction in human obesity: fibre type, enzymatic(beta)-oxydative capacity and fatty acid-binding protein content. *European Journal of Clinical Investigation*, 28, 1030-1037.
14. Klusiewicz, A., Trzaskoma, Z., Borkowski, L., & Starczewska-Czapowska, J. (2004). Assessment of specific work capacity of elite cross-country skiers and biathletes. *Physical Education and Sport*, 48 (3), 215-221.
15. Koul, H., & Qian, L. (2002). Asymptotics of maximum likelihood estimator in a two-phase linear regression model. *Journal of Statistical Planning and Inference*, 108, 99-119.
16. McLellan, T. (1985). Ventilatory and plasma lactate response with different exercise protocols: a comparison of methods. *International Journal of Sports Medicine*, 6, 30-35.
17. Myers, J., & Ashley, E. (1997). Dangerous curves. A perspective on exercise, lactate and the anaerobic threshold. *Chest*, 111, 787-795.
18. Meyer, T., Faude, O., & Scharhag, J. (2004). Is lactic acidosis a cause of exercise induced hyperventilation at the respiratory compensation point? *British Journal of Sports Medicine*, 38, 622-625.

19. Peronnet, F., & Massicotte, D. (1991). Table of nonprotein respiratory quotient: an update. *Canadian Journal of Applied Sport Sciences*, 16, 23-29.
20. Reinhard, U., Miller, P., & Schmьlling, R. (1979). Determination of anaerobic threshold by the ventilation equivalent in normal individuals. *Respiration*, 38, 36-42.
21. Robergs, A. (2001). Interpretations of the VO2max Concept. *Journal of Exercise Physiology online,* 4 (1), 1-44.
22. Schutz, Y. (1995). Abnormalities of fuel utilization as predisposing to the development of obesity in humans. *Obesity Research*, 3, 173-178.
23. Solberg, G., Robstad, B., Skjønsberg, O., & Borchsenius, F. (2005). Respiratory gas exchange indices for estimating the anaerobic threshold, *Journal of Sports Science and Medicine*, 4, 29-36.
24. Stuart, A., Ord, K., & Arnold S. (1999). *Kendall's Advanced Theory of Statistics*. 6th ed. London: Arnold.
25. Svedenhag, J., & Sjödin B. (1985). Physiological characteristics of elite male runners in and off-season. *Canadian Journal of Applied Sport Sciences*, 10, 3, 127-133.
26. Tanaka, H., Monahan, K., & Seals, D. (2001). Age – predicted maximal heart rate revisited. *Journal of the American College of Cardiology*, 37, 153-156.
27. Wasserman, K., & McIlroy, M. (1964). Detecting the threshold of anaerobic metabolism in cardiac patients during exercise. *American Journal of Physiology*, 14, 844-52.
28. Wasserman, K., Whipp, B., Koyal, S., & Beaver. W. (1973). Anaerobic threshold and respiratory gas exchange during exercise. *Journal of Applied Physiology*, 35, 236-243.
29. Wasserman, K., Hansen J., Darryl, Y., & Whipp, B (2005). *Principles of exercise testing and interpretation*. 4th ed. Philadelphia: Lippincott Williams&Wilkins.
30. Yeh, M., Gardner, R., Adams, T., Yanowitz, F., & Crapo, R. (1983). "Anaerobic threshold": problems of determination and validation. *Journal of Applied Physiology*, 55, 1178-1186.

PROBLEM ODREĐIVANJA VENTILATORNOG PRAGA BAZIRANOM NA RASPONU RESPIRATORNE RAZMENE KOD VRHUNSKIH SPORTISTA

Stanislav Tzvetkov, Peter Bonov, Daniela Dasheva

Kao alternativu invazivniom određivanju laktatnog anaerobnog praga, brojne metode detekcije ventilatornog praga (VT) su korišćene – upotrebom raspona respiratorne razmene ($VT_{RER=1.0}$), tačka prekida nelinearnog povećanja ventilatornog ekvivalenta za kiseonik (VT_{EqO2}) i kriva Vco_2 u odnosu na Vco_2 ($VT_{V\text{-}slope}$). Neki autori identifikuju tačku respiratorne kompenzacije (RCP), drugi postavljaju pitanje tačnosti VT_{RER} metode. Cilj je bio da se uporede rezultati za $VT_{RER=1.0}$, VT_{EqO2}, $VT_{V\text{-}slope}$ i RCP kod 18 muškaraca, visoko kvalitetnih sportista iz aerobnih sportova. U One-Way ANOVA testu značajnosti razlika je pokazano da postoje uzajamne vrednosti VO_2 i radnog kapaciteta ($F = 7,95$ and $F = 14,53$; $p < 0,05$) u paru $VT_{V\text{-}slope}$ - $VT_{RER=1.0}$, $VT_{V\text{-}slope}$ - RCP, VT_{EqO2} - $VT_{RER=1.0}$ i VT_{EqO2} - RCP. Višestruka parovna komparativna analiza za VO_2 i radni kapacitet otkrila je nedostatak prihvatljive statističke uzajamnosti $VT_{RER=1.0}$ sa $VT_{V\text{-}slope}$ i VT_{EqO2}.

Ključne reči*: respiratorna razmena gasova, ventilatorni prag, comparativna analiza*