Activities in Physical Education and Sport
2017, Vol. 7, No. 1, pp. 95-99

INDICATORS OF EFFECTIVENESS AND ECONOMY IN EVALUATION OF FUNCTIONAL WORKING CAPABILITY OF ELITE ATHLETES

(Review)

Stanislav Tzvetkov
National Sports Academy "Vassil Levski"
Department of Sport medicine, Sofia, Bulgaria

Abstract

Maximal oxygen consumption (VO_{2max}) is a key parameter for maximal functional capacity assessment of athletes. However, an extremely high VO_{2max} is not the only determinant of athletic performance and success. Researches have found wide variations in improvement of VO_{2max} with specific aerobic training. Furthermore, high level athletes very often show a smaller increase in VO_{2max} compared to beginners. Another important physiological factor, which determines the ability for continuous exercise is the anaerobic threshold. According to some authors, anaerobic threshold is the main scientific criterion, which corresponds to the acceptably of the race performance and can be used for prescribing intensity during competition. They also comment that it can be used as an indirect criterion of the effectiveness of functional processes in high level athletes. Other scientists highlight that sport shape and results are also determined by factors, related to the economy of functional processes in the organism. They agree that the assessment of functional capabilities should also include an analysis of the parameters, characterizing the body economy during prolonged exercise. In the present work we review the basic methods for determining of anaerobic threshold and complex economy of the body during running (running economy). Moreover, we analyse the analytical importance of these physiological factors in the complex assessment of the functional working capability of elite athletes.

Keywords: *anaerobic threshold, effectiveness and economy of the functional processes, maximal oxygen consumption, athletic performance, aerobic-anaerobic processes, muscle fatigue*

INTRODUCTION

The ability of the organism to perform continuous motor activity is determined by the balance between production and realization of energy in the working musculature. During prolonged exercise at high intensity (over 80% of maximal oxygen consumption) cardiovascular system, due to its limited adaptive capacity, is unable to convey an adequate amount of oxygen to the working musculature, which limits the aerobic metabolism (Fox, Keteyian, & Foss, 1998). This physiological process results in activation of anaerobic glycolysis and causes increased production of lactate with poor dynamic balance of aerobic-anaerobic processes (Owles, 1930). It has been found that increased cellular accumulation of lactate and the conditioned by this process reduction in pH create preconditions for muscle fatigue (MacRae, Dennis, Bosch &, Noakes, 1992). As a result the "critical threshold" is observed of physical exercise intensity in the realization of continuous physical activity. Physical exercise with intensity above the "critical threshold" is characterized by rapid onset of muscle fatigue. This threshold is referred to as "anaerobic threshold" and it is assumed that this is "the intensity of physical exercise or the corresponding oxygen consumption of occurrence of metabolic acidosis and related changes in respiratory parameters" (Wasserman, Whipp, Koyal, & Beaver,1973).

According to Davis, Vodak, F., Wilmore, Vodak, J., & Kurtz (1976), in conducting intensive training of elite athletes, aiming to improve endurance, dynamics in anaerobic threshold is observed, without a concomitant increase in maximal oxygen consumption (VO_{2max}). Based on this result authors suggest that these two indicators have different physiological mechanisms of adaptation and it is not necessary that the positive changes as a result of effective training process at one of them is accompanied by changes in the other. Moreover the increase in VO_{2max} in conducting the adequate training load depends to a considerable extent by genetic factors, so in different individuals different dynamics in VO_{2max} is observed, despite of training program held in the same volume and intensity (Bouchard et al., 1999**)**. In this regard, some authors assume that compared to VO_{2max} the anaerobic threshold analysis is more precise criterion to objectively predict the sports performance in endurance disciplines (Bassett & Howley, 2000).

Basic methods for determining the anaerobic threshold

The concept of anaerobic threshold is applied through two main methodological aspects, namely by defining lactate and ventilatory anaerobic threshold (McArdle, Katch F., Katch V., 2009).

Lactate anaerobic threshold:

Reflects the intensity of the physical exercise, which demonstrates significant increase in lactate concentration in the blood. There are different methodological approaches to determine the lactate anaerobic threshold (Bosquet, Leger, & Legros, 2002). The analysis of contemporary points of view in this field of science confirms the standpoint, that the most commonly applicable classic method is the one, in which the lactate anaerobic threshold is defined by the so called "lactate dynamics breakpoint" (Tzvetkov (Цветков), 2010). This approach determines the inflection point in the dynamics of lactate values (lactate anaerobic threshold – AT), characterizing the beginning of a significant increase in the lactate concentration in testing with increasing intensity of physical exercise (Kenney, Wilmore & Costill, 2011).

Ventilatory anaerobic threshold:

Ventilatory anaerobic threshold is defined as intensity of physical exercise, which is related to marked increase in pulmonary ventilation, coupled with change in dynamics in other parameters of respiratory metabolism (respiratory rate, tidal volume, respiratory exchange ratio).

Physiological equivalent of ventilatory anaerobic threshold corresponds to the increased concentration of lactate in the blood and the conditioned by the latter significant decrease in the pH (pH<7.35), which in depletion of the capacity of the buffer systems of the organism leads to compensatory stimulation of pulmonary ventilation (McArdle, Katch F., Katch V., 2009). It has been found that increased concentration of hydrogen ions (H^+) has direct impact on the chemoreceptors in the brainstem, directly stimulating the pulmonary ventilation (Nattie & Li, 2009). The end result of this compensatory mechanism is significant increase in lung ventilation and change in the discussed respiratory parameters in intensity load above the anaerobic threshold (Fig. 1.).

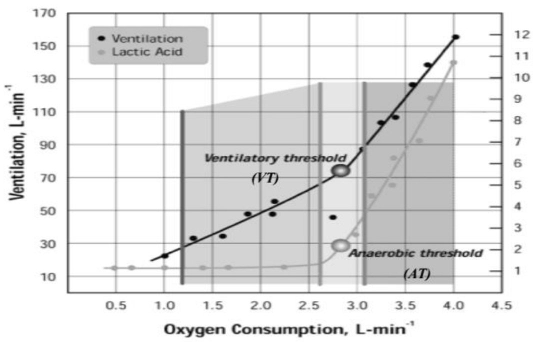

Fig. 1. Functional relationship between dynamics of lactate concentration, lactate anaerobic threshold (AT) and ventilatory anaerobic threshold (VT) (Foster & Porcari, 2010)

Research practice uses a variety of methodological approaches for the identification and interpretation of lactate and ventilatory anaerobic threshold, which have been studied in detail (Bosquet et al., 2002; Wasserman et al., 2011). This fact motivates us to focus the essence of the material on the informative significance of this functional indicator for complex evaluation of the functional capabilities of athletes.

Analytical importance of anaerobic threshold

Modern scientific position highlights that good sports shape and sports results are not determined only by increase in maximal aerobic capacity (VO_{2max}), but also by factors, related to the economy and effectiveness of functional processes in the organism, as well as by high tolerance to the concentration of lactate in muscle cells (McArdle et al., 2009). This statement is especially important for professsional athletes, who have built functional capabilities (Sjödin & Svedenhag**,** 1985). According to Bentley & McNaughton (2003), highly skilled athletes are characterized by limited information value of VO_{2max} in assessing the fitness level. Authors comment that in elite athletes changes in this indicator should not be used as a primary criterion for predicting athletic performance. They are based on the fact that in highly skilled athletes VO_{2max} values are close to the maximal physiological limits, ma-king it difficult to achieve their considerable increase as a result of optimizing the training process. In these circum-stances the athletes, who are characterized by higher eff-iciency of the aerobic-anaerobic metabolism, will achieve better competitive result.

It is known that realization of prolonged, intense motor activity depends on the dominant role of aerobic processes (Fox et al., 1998). When under intense physical exercise the organism utilizes greater amount of oxygen, it is logical that high level of aerobic metabolism will be maintained longer. As a result of this process cell metabolism will optimize, which would lead to limited accumulation of lactate and prolonged physical performance (Thompson, Gorden & Pescatello, 2009). *Based on the presented physiological mechanisms, registered oxygen consumption in intensive physical exercise, corresponding to the anaerobic threshold (AT), is used as an indirect criterion of the effectiveness of functional processes in the organism* (Bassett & Howley, 2000). According to the adopted approach for assessment, registered oxygen consumption in intensive load, corresponding to AT, is presented as a percentage of the maximal oxygen consumption.

In conducting training loads in order to develop the aerobic capacity, complete functional effect determines the "shift of the anaerobic threshold to the right" to a higher in intensity physical load (Fig. 2.).

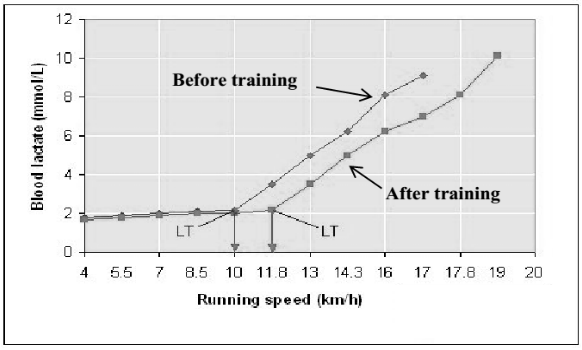

Fig. 2. Lactic anaerobic threshold before and after realization of systematic training process (before training; after training) (Davies, 2011)

The shift of anaerobic threshold is a result of complex improvement of functional processes, which ensures more complete use of the aerobic capacity of the organism. These changes are due primarily to increases in muscle capillary and mitochondrial density, as well as metabolic activity of oxidative enzymes in mitochondrial respiratory chains (Kenney et al., 2011). From a physiological point of view "the shift of AT to the right" determines delayed dominance of anaerobic processes with delayed reach of critically high lactate values and occurrence of muscle fatigue. At the same time "the shift of AT to the right" leads also to the registration of higher values of the oxygen consumption, corresponding to the anaerobic threshold.

Because of the described adaptive changes elite athletes have higher oxygen consumption in load intensity, corresponding to AT, which creates prerequisites for realization of better athlete achievements in endurance sports. McArdle et al. (2009) comments that in healthy, non-sports subjects aged up to 40 years, oxygen consumption, corresponding to the individual anaerobic threshold, is about 55% of VO_{2max}. In qualified athletes of endurance sports as a result of continuous and systematic training process oxygen consumption values, corresponding to AT, are significantly higher (80-90% of VO_{2max}).

Economy of the organism when running (running economy)

Some experts agree that good sports shape and results are also determined by factors, related to the economy of functional processes in the organism (Wasserman et al., 2011). Therefore, they recommend that complex assessment of functional capabilities should also include a detailed analysis of the indicators, characterizing the economy of the organism in the performance of long-term physical load. The actuality of this analytical approach is highlighted in the modern study of Mclaughlin, Howley, Basset, Thompson & Fitzhugh (2010). Authors explore the main physiological factors that are crucial to accurate prognosis of sports result in medium and long distance running (Fig. 3).

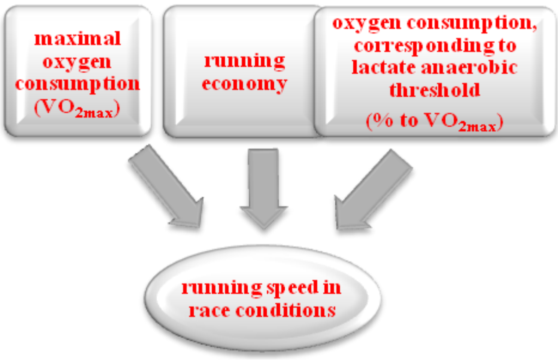

Fig. 3. Main physiological factors that determine the competitive achievement in medium and long distance running (Mclaughlin et al., 2010)

They believe the good performance of the athletes in these disciplines is determined by the synchronized interaction of three main physiological factors – *maximal aerobic capacity (VO_{2max}), complex economy of the organism when running (running economy) and oxygen consumption in intensity of physical activity, corresponding to lactate anaerobic threshold.* The authors point out that compared to other described factors, the high values of maximal oxygen consumption are crucial for the realization of high speed competitive running. At the same time they comment that long-term keeping (more than 10-15 min) of high speed of running requires economy and high effectiveness of the performed motor activity. Therefore they agree that the complete realization of the existing aerobic capacity of the organism depends on the optimal economy of the realized physical efforts (running economy) and effectiveness of muscle metabolic processes (high values of the oxygen consumption, corresponding to the anaerobic threshold).

Determining economy when running (running economy)

From a theoretical perspective precise examination of the economy of the organism when running is a very complex process. This is due to the fact that this functional indicator depends on metabolic, cardiovascular, neuromuscular and biomechanical factors (Anderson, 1996). This fact has motivated scientists to study the economy (including that of aerobic metabolism) by measuring the "oxygen cost" (oxygen consumption) of motor activity performed (Daniels, 1985).

Some authors believe that this indicator can be analyzed by measuring oxygen consumption, which corresponds to the lactate anaerobic threshold (Conley & Krahenbuhl, 1980). This view is controversial and differs from the conventional opinions. *Modern scientific concept assumes that it is recommended the economy of realized physical exercises to be analyzed by registration of the oxygen consumption in a "steady state" (functionally dynamic balance) condition of moderate intensity exercise (12 km/h; 14 km/h)* (Saunders, Pyne, Telford & Hawley, 2004; Mclaughlin et al., 2010).

In contrast to this methodical approach, the oxygen consumption, corresponding to the lactate anaerobic threshold, is studied by stepwise protocol of functional testing and is registered by physical exercise of submaximal intensity. From the standpoint of analytic interpretation in conducting stepwise functional test, due to shift of the anaerobic threshold to a higher intensity of physical exercise, it is possible to register higher values of the oxygen consumption, corresponding to the anaerobic threshold. These results will testify for more effective use of existing aerobic capacity, which determines limited accumulation of lactate and delayed the onset of muscle fatigue.

It is necessary to emphasize that the physiological relationship between the two functional indicators is under study, thus the described differentiation in the methods of the study is conditional. On the other hand, some experts reasonably point out that by their nature the terms "economy" and "effectiveness" overlap to some extent (Barnes & Kilding, 2015). *They recommend that in complex analysis the discussed parameters should not be considered separately, but in the context of close interdependence.*

It is assumed that low "oxygen cost" of performed motor activity is an essential criterion for assessing functional abilities of athletes in endurance disciplines (Mclaughlin et al., 2010). This motivates us to describe the methodological characteristics of a study of the functional parameter "running economy". In his review publication Barnes & Kilding (2015) underlines that the economy of the realized physical activity is an integral indicator that depends on the intensity of the metabolic processes, function of the cardiovascular system and the neuromuscular mechanisms, as well as of the biomechanical completeness of the movements. From this perspective we can point out that this indicator characterizes not only the activity of the muscle power, providing processes, but also the complex interaction of functional systems, determining optimal motor activity.

As we mentioned in comparison with anaerobic thre-shold the economy of motor activity (running) is examined by different methodical approach. This approach consists in the measurement of oxygen consumption in treadmill running at a constant speed (12-16 km/h) within 4-15 min. Important methodical requirement is that the intensity of physical exercise is moderate, so that it determines constant low values of blood lactate concentration (2-2.5 mmol/l) and respiratory exchange ratio (RER<1.00) (Barnes & Kilding, 2015). The aim is power delivery of physical exercise to be realized predominantly by aerobic processes, which determines sufficiently the informative analysis of aerobic capabilities. Additional feature is the fact that the organism is studied in steady dynamic balance ("steady state"), which is a result of adaptation of the physiological systems of the organism to long-term running at a constant speed.

The analytical approach of the assessment consists in comparison of the oxygen consumption ("oxygen cost") of the realized physical activity of moderate intensity in athletes with comparable values of VO_{2max} (Fig. 4,).

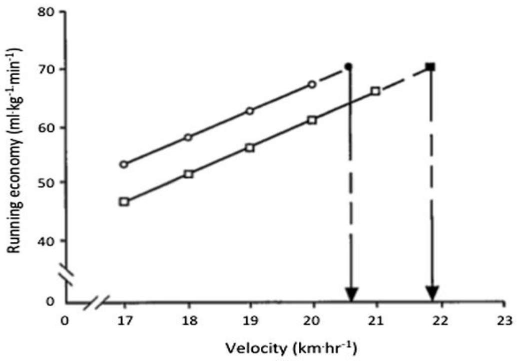

Fig. 4. Realized maximal speed in persons with equivalent maximal oxygen consumption and different economy ***(Barnes & Kilding, 2015)***

In Fig. 4. the competitor with lower "oxygen cost" (better economy) realizes greater maximal ergometric performance (maximal speed), compared to the one that has the same maximal oxygen consumption, but higher "oxygen cost" (oxygen consumption) of motor activity and lower maximal performance. In these circumstances it is evident that the athlete with registered lower "oxygen cost" utilizes more economically their aerobic capacities and will have functional advantage in contest participation.

Analytical meaning of economy when running (running economy)

Because the running economy is measured and evaluated by "the oxygen cost" of performed motor activity, researchers use this indicator for indirect assessment of the aerobic capacity utilization of the body **(**Daniels, 1985; Saunders et al., 2004; Mclaughlin et al., 2010). They are based on the physiological rationale that the "oxygen cost" characterizes the cellular metabolic processes and the fact that during the exercise of moderate intensity (12-17 km/h) the aerobic processes have dominant importance in the power delivery process. In this context experts emphasize that when examining running economy the intensity of physical activity is significantly lower than the one, at which the anaerobic threshold is analyzed (Morgan, Martin & Krahenbuhl, 1989). Therefore, some authors accept that from a methodological point of view, running economy should not be seen as identical to anaerobic threshold functional indicator (Saunders et al., 2004).

According to Mclaughlin et al. (2010) the analytical interpretation of both indicators is also different. In the physiological aspect it is known that motor activity at moderate intensity is performed by the dominance of aerobic energy processes, but the submaximal exercise is characterized with borderline dominance of anaerobic metabolism (Wasserman et al., 2011). It is possible after realizing of the complete training process, in testing the athlete with moderate physical load and in a functionally dynamic balance ("steady state"), to register lower oxygen consumption. In the context of the dominant aerobic power delivery, registered lower levels of oxygen consumption may reasonably be interpreted as a lower "oxygen cost" of the performed motor activity and improved economy.

A similar indicator for the economy is also applicable in the research practice in Bulgaria. When testing athletes with a treadmill through specific for our country stepwise protocol, the so called "indicator for aerobic metabolism economy" is used (Iliev (Илиев), 1974). It represents "the oxygen cost" of the realized motor activity at a moderate running speed (12 km/h) in the course of a stepwise physical exercise with increasing intensity. It is necessary to specify that the commented indicator is analyzed by measuring the oxygen consumption during moderate physical exercise within one step (duration 90 sec). It is undisputed that in the applied methodical approach the duration of running at a speed of 12 km/h is very short, so that the functional systems of the organism do not reach a state of stable dynamic balance ("steady state"). The mentioned circumstance compromises the analytical value of this functional indicator and explains its limited applicability.

CONCLUSION

In conclusion we can summarize that the analysis of the economical and effective use of the functional abilities of the organism has great practical application in testing qualified athletes. In terms of real competition the abilities of the organism for the realization of continuous motor activity with optimal intensity are crucial for high competitive score. These abilities are determined by both the high values of maximal oxygen consumption and the economy of the performed motor activity and the complete usage of the existing aerobic capacity of the athlete. These circumstances determine the need for routine use of the indicators discussed in examination and evaluation of the functional characteristics of professional athletes in endurance sports. The study of economy and effectiveness of the performed motor activity may be crucial in the complex assessment of the optimal functional training of professional athletes, not only in athletics, but also in other sports disciplines like cycling, orienteering, biathlon, rowing, canoeing, swimming and others.

REFERENCES

Anderson, T. (1996). Biomechanics and running economy. *Sports Medicine*, *22*(2), 76-89.

Barnes, K., & Kilding A. (2015). Running economy: measurement, norms, and determining factors. *Sports Medicine Open Journal*, *1*(8), 1-15.

Basse, D., & Howley, E. (2000). Limiting factors for maximal oxygen uptake and determinants of endurance performance. *Medicine and Science in Sports and Exercise*, *32*(1), 70-84.

Bentley, D., & McNaughton, L. (2003). Comparison of wpeak, VO2peak and the ventilation threshold from two different incremental exercise tests: relationship to endurance performance. *Journal of Science and Medicine in Sport*, *6*(4), 422-435.

Bosquet, L., Leger, L., & Legros, P. (2002). Methods to determine aerobic endurance. *Sports Medicine*, *32*(11), 675-700.

Bouchard, C., Ping, A., Treva, R., Skinner, J., Wilmore, J., Gagnon, J., … Rao, D. (1999). Familial aggregation of $VO_{2\,max}$ response to exercise training: results from the heritage family study. *Journal of Applied Physiology*, *87*(3), 1003-1008**.**

Conley, D., & Krahenbuhl, G. (1980). Running economy and distance running performance of highly trained athletes. *Medicine and Science in Sports and Exercise, 12*(5), 357-360.

Daniels, J. (1985). A physiologist's view of running economy. *Medicine and Science in Sports and Exercise, 17*(3), 332-338.

Davies, P. (2011). The lactate threshold. *Sports Advisor*. From: http://www.sport-fitness-advisor.com/.

Davis, J., Vodak, F., Wilmore, J., Vodak, J, & Kurtz, P. (1976). Anaerobic threshold and maximal aerobic power for three modes of exercise. *Journal of Applied Physiology, 41*(4), 541-550.

Foster, C., Porcari, J. (2010). Validating the talk test as a measure of exercise intensity. *American Council on Exercise*, 1-3. From: http://www.acefitness.org/certifiednewsarticle/888.

Fox, E., Keteyian. S., & Foss, M. (1998). *Fox's Physiological Basis for Exercise and Sport*. 6th ed., Boston: William C Brown Pub.

Илиев, И. (1974). *Методика за комплексно изследване на спортисти от висока класа* [Methods of complex examination of high-level athletes. In Bulgarian.] София: БСФС ПРЕС.

Kenney, L., Wilmore, J., & Costill, D. (2011). *Physiology of sport and exercise*. 5th ed. Champaign, IL,: Human Kinetics Press.

McArdle, W., Katch, F., & Katch, V. (2009). *Exercise Physiology: Energy, Nutrition and Human Performance*. 7th ed., Philadelphia: Williams & Wilkins.

Mclaughlin, J., Howley, E., Basset, D., Thompson, D., & Fitzhugh, E. (2010). Test of the classic model for predicting endurance running performance. *Medicine and Science in Sports and Exercise, 42*(5), 991-997.

Morgan, D., Martin, P., & Krahenbuhl, G. (1989). Factors affecting running economy. *Sports Medicine, 7*(5), 310-330.

Nattie, E., & Li, A. (2009). Central chemoreception is a complex system function that involves multiple brain stem sites. *Journal of Applied Physiology, 106*(4), 1464-1466.

MacRae, H., Dennis, S., Bosch, A., & Noakes, T. (1992). Effects of training on lactate production and removal during progressive exercise in humans. *Journal of Applied Physiology, 72*(5), 1649-1656.

Owles, W. (1930). Alterations in the lactic acid content of the blood as a result of light exercise, and associated changes in CO2 combining power of the blood and into alveolar CO2 pressure. *Journal of Physiology, 69*(2), 214-237.

Saunders, P., Pyne, D., Telford, R., & Hawley, J. (2004). Factors affecting running economy in trained distance runners. *Sports Medicine, 34*(7), 465-485.

Sjödin, B., & Svedenhag, J. (1985). Applied physiology of marathon running, *Sports Medicine, 2*, 83-99.

Thompson, W., Gorden, N., & Pescatello, L. (2009). *ACSM's Guidelines for Exercise Testing and Prescription*. 8th ed. Philadelphia: Williams & Wilkins.

Wasserman, K., Whipp, B., Koyal, S., & Beaver, W. (1973). Anaerobic threshold and respiratory gas exchange during exercise. *Journal of Applied Physiology, 35*(2), 236-243.

Wasserman, K., Hansen, J., Sue, D., Stringer, W, Sietsema, K., & Sun, X. (2011). *Principles of exercise testing and interpretation*. 5th ed. Philadelphia: Williams & Wilkins.

Цветков, С. (2010). *Сравнителен анализ на методите за определяне на анаеробния праг* [Comparative analysis of the methods for anaerobic threshold determination. In Bulgarian.] (Unpublished doctoral dissertation, National Sports Academy, Sofia) София: Факултет по Кинезитерапия, туризъм и спортна анимация.

Correspondence:
Stanislav Tzvetkov
National Sports Academy “Vassil Levski”
Studentski Grad, Sofia 1700, Bulgaria
Department of Sport medicine
E-mail: st.tzvetkov@gmail.com