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REVIEW ARTICLE

The underpinning of the evaluation of aerobic endurance based on methods established in the late 20th century: A systematic review

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Abstract

This systematic review aims to analyze the validity (invasive and noninvasive protocols) of aerobic endurance evaluation methods established in the late 20th century and their practical application in creating training series in different sports events. The PRISMA system was used for systematic review. It was identified that high number of studies support the concept of the evaluation of aerobic endurance, i.e., aerobic threshold (AnT), in terms of its significance for the determination of training series and training intensity aimed at aerobic endurance improvement. During the protocol of testing and construction of the lactate curve (La – work capacity), the method based on sampling and measurement of lactate concentration in blood is given priority as a more valid instrument for AnT determination than the method based on ventilatory parameters and heart frequency. Authors note that the parameters based on which AnT is determined are expressed in different units of measure (m/min, km/h, ml/kg/min) so that AnT, as such, does not only represent the measure of aerobic endurance but also the measure of maximal oxygen consumption (VO2max) and mechanical efficiency. The results of the study indicate that terms related to AnT should be removed from official use. More precisely, researchers and coaches focus on a method related to the interpretation of the lactate curve (at a certain %VO2max) to determine whether there has been an improvement (or not) in aerobic endurance based on its displacement (to the right or to the left).

Keywords: anaerobic threshold · lactate threshold · ventilatory threshold

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Introduction

There are numerous parameters for determining aerobic abilities: aerobic power or maximal oxygen consumption (VO2max), work efficiency, the time constant of VO2 kinetics, and lactate threshold. Maximal oxygen consumption is a highly significant indicator of a man's physical abilities since it represents an upper limit of exercise tolerance under aerobic work conditions (Whipp et al., 1981). Activities with the predominant component of aerobic endurance get performed at a particular percentage (% VO2 max) of maximal oxygen consumption. If values of VO2max are extremely low, performance efficiency will be low too.

Prediction methods of aerobic endurance draw on the relationship between the usage percentage of VO2max and particular biological variables such as ventilation parameters, lactate concentration in blood (La), and heart frequency values. In theory, this relationship is accounted for by the term "threshold." The threshold is the level at which changes in physical parameters occur as a reaction to particular stimuli. Below the threshold level, a stimulus is not sufficient to cause changes, but above the threshold level, it causes the expected reactions (Tokmakidis, 1990).

As early as 1932, Olives et al. were among the first ones who claimed changes in lactate concentration after applying a low-intensity exercise. Wasserman et al. (1973) reported that changes in lactate concentration are related to the changes in particular ventilatory parameters during the testing protocol with a gradually increased workload. Authors accounted for these changes as Anaerobic threshold (AnT), i.e., work intensity or the percentage of the value of maximal oxygen consumption at which changes occur in terms of increased metabolic acidosis, as well as gas exchange (Wasserman et al., 1973). According to the above arguments, an athlete who trains at an intensity lower than the threshold will be able to tolerate lactate concentration (La) and hydrogen ions (H+) in working muscles, and the resulting fatigue will only be the consequence of the consumption of energy reserves in the body. Accordingly, the higher the threshold, the higher the level of aerobic endurance (Péronnet et al., 1987). It is important to note that the AnT is not the threshold of anaerobiosis. Not only is the contribution of anaerobic systems small during exercising at sub-maximal intensity (intensity lower than VO2max), but lactate creation during exercising can result from the higher-than-required pyruvate production, which is not contingent on the anaerobic mechanism (Connet, 1984). Lactates can be produced both in oxidative and glycolytic muscle fibers (Connet, 1984). Even though the use of the term "anaerobic" is incorrect, the fact is that the so-called AnT correlates highly with VO2max usage percentage for a given activity (Noakes, 1997). Complying with the above, the AnT represents a reliable parameter for the evaluation of aerobic endurance. By application of invasive and noninvasive testing protocols with a constant workload and protocols with a gradually increased workload, researchers tried to define and locate AnT as precisely as possible. Thus, this systematic review aims to analyze the validity (invasive and noninvasive protocols) of aerobic endurance evaluation methods established in the late 20th century and their practical application in creating training series in different sports events.

Method

Search strategy

For the purposes of this systematic review follows the guidelines set by the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) protocol (Page et al., 2021). Studies involving methods for assessing aerobic endurance in the second half of the 20th century were selected. Electronic sources were searched in 5 research databases during January and February 2024. PubMed, SCIndeks, J-GATE, DOAJ, and Google Scholar databases were used. The search was based on the following keywords: "aerobic endurance", "cyclical sports", "aerobic capacity", "methods of aerobic capacity", "anaerobic threshold", "lactate threshold", "ventilatory threshold". These keywords were used separately or in combination with AND. Also, the references of all selected studies and relevant systematic reviews were manually checked for additional researches.

Inclusion and exclusion criteria

The study inclusion criteria are as follows: 1) studies the second half of the 20th century 2) include a type of cyclic sports activity 3) treat aerobic endurance 4) invasive and non-invasive assessment methods. The criteria for not including the study are as follows: 1) studies that were published before 1950 and after 2000. 2) experimental studies 3) studies that treat acyclic sports activities 4) studies that have not been published in English and German.

Quality of assessment

The initial identification yielded 462 potentially relevant studies (studies with relevant title and abstracts), also included the additional records 27 (reports of relevant institutions, PhD research papers), from which 51 duplicates were eliminated using EndNote 20's automated tool (Clarivate Analytics, EndNote, 2020). Additionally, the manual review led to the elimination of 41 more duplicates, while seven non-English and three non-German studies were further removed. The remaining 64 studies were screened for title and abstract relevance. Subsequently, two screeners reviewed the full text and included 11 as eligible studies. Any conflict between screeners regarding eligibility was resolved through discussions, and the Cochrane RoB tool was used to assess the risk of methodological bias The PRISMA chart that summarizes these processes can be seen in Figure 1.

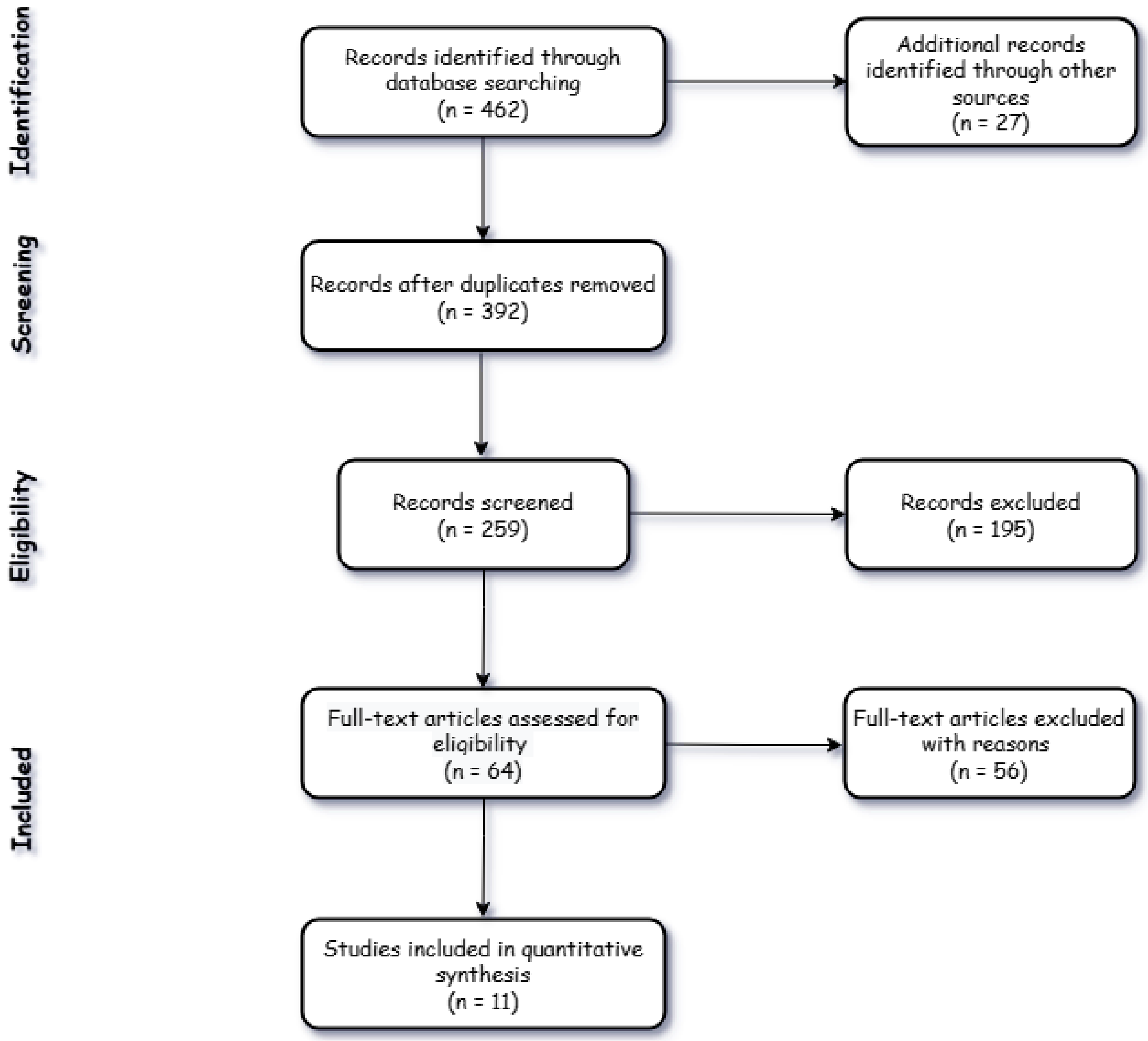

Figure 1. PRISMA flow chart

Results

The evaluation of study quality was conducted utilizing the Page et al (2021) checklist, which has 27 items. The basic characteristics of the included studies include the application of cyclic activity and protocols of invasive and non-invasive methods for the assessment of aerobic endurance (Table 1). Separate studies (11 of them) in their protocols apply cyclic activities (running, pedaling, rowing) in laboratory conditions, and all subjects were subjected to invasive (4 studies) and non-invasive methods (7 studies) in which lactate accumulation and impact on aerobic endurance were evaluated. Invasive protocols in which blood lactate was assessed according to Sjödin & Jacobs (1981) indicate that marathon running is closely related to the onset of lactate accumulation (OBLA), on the other hand, confirms that the practical application of anaerobic threshold (AT4), as well as individual anaerobic threshold (IAT) do not represent maximal lactate steady state workload. Studies in which non-invasive protocols were applied (Sheen et al., 1981) indicate that there is no evidence that the hyperventilation threshold is necessarily an anaerobic threshold and that it is also a critical

Table 1. Characteristics of studies included in the review - (invasive and noninvasive protocols)

Study	Journal	Activity type	Method/Model	Conclusion	Outcomes
Ivy et al. (1980)	*Journal* of *Applied Physiology*	Cyclical - pedaling	Invasive / lactate threshold	Muscle's respiratory capacity is of primary importance in determining the work rate at which blood lactate accumulation begins.	21/27
Sjödin & Jacobs (1981)	*International Journal* of *Sports Medicine*	Cyclical - running	Invasive / OBLA	Marathon running performance was closely related to OBLA and to the ability to run at a pace close to that velocity during the race	19/27
LaFontaine et al. (1981)	*Medicine* & *Science* in *Sports* & *Exercise*	Cyclical - running	Non-Invasive / MSS	Data indicate that the pace for essentially aerobic events can be closely approximated by knowledge of a runner's MSS, or conversely that the MSS can be predicted very closely from the pace of running.	21/27
Stegmann, et al. (1981)	*International Journal* of *Sports Medicine*	Cyclical - running	Non-Invasive / IAT	In general, increasing aerobic capacity the lactate concentration at the IAT decreases, but the lactate concentration at the IAT varies interindividual within broad limits.	23/27
Wasserman et al. (1985)	*Journal* of *Applied Physiology*	Cyclical –ride (cycle ergometer)	Ivasive / Pyruvate threshold	The resulting increase in Lactate and Pyruvate ratio is progressive as work rate is incremented and abruptly reverses when exercise stops.	23/27
Wasserman et al. (1973)	*Journal* of *Applied Physiology*	Cyclical - pedaling	Non-Invasive / Anaerobic threshold	The anaerobic threshold is a useful concept Its application during exercise testing indicates information about cardiovascular function	23/27
Beneke (1995)	*Medicine* & *Science* in *Sports* & *Exercise*	Cyclical – rowing	Ivasive / MLSS	Independent of the practical application of AT4 and IAT, do not represent MLSS workload.	23/27
Sheen et al. (1981)	*European Journal of Applied Physiology*	Cyclical – walking (treadmill)	Non-Invasive /Hyperventilatory threshold	There is no evidence that the "hyperventilation threshold" necessarily represents an "anaerobic threshold", i.e., a critical intensity of exercise inducing an insufficient oxygen delivery to the muscles.	23/27
Boulay, et al. (1984)	*Canadian Journal of Applied Sport Sciences*	Cyclical –ride (cycle ergometer)	Non-Invasive /Maximal aerobic capacity	The Maximal aerobic capacity should be useful in the study of the effects of training especially when the training program is a long duration.	24/27
Gladden et al. (1985).	*Journal of Applied Physiology*	Cyclical - pedaling	Non-Invasive / Gas exchange threshold	The results suggest that anaerobic threshold determinations by gas exchange methods do not agree with the same determinations by blood lactate changes.	24/27
Palka & Rogozinski (1986)	*European Journal of Applied Physiology*	Cyclical - pedaling	Non-Invasive / Respiratory anaerobic threshold	The correlation of VO_2max relating muscularity and vital lung capacity is positive and statistically significant, maximal oxygen uptake allowed to calculate regression lines which could be used as nomograms of predicted AT values.	24/27

MMS = maximal steady state / condition; IAT = individual aerobic threshold; MLSS = maximal lactate steady state; AT4 = anaerobic threshold; AT = anaerobic threshold intensity that is associated with insufficient oxygen delivery in the muscles. Too, that the determination of the anaerobic threshold based on gas exchange does not agree with the identified changes in blood lactate (Gladden et al., 1985).

Discussion

Lactate threshold (LT)

The beginning of lactate accumulation in the blood (OBLA) (Ivy et al., 1980), lactate threshold (Sjödin & Jacobs 1981), individual anaerobic threshold (Stegmann et al., 1980), lactate curve index (Hughson et al., 1987) is just some of the terms used for the determination of exercise intensity at which nonlinear increase of the concentration (La) occurs. For a list of terms used in various research sources, see Table 2.

Table 2. Different nomenclatures for the AnT description

Study	Nomenclature
Invasive methods	
Ivy et al.	Lactate threshold
Skinner & McLellan	Aerobic threshold
Sjödin & Jacobs	Beginning of lactate accumulation in the blood
La Fontaine et al.	Maximal stability state / condition
Wasserman et al.	Pyruvate threshold
Beneke	Maximal lactate steady state
Noninvasive methods	
Wasserman et al.	Anaerobic mechanism threshold
Stegmann et al.	Individual aerobic threshold
Scheen et al.	Hyperventilatory threshold
Boulay et al.	Ventilatory anaerobic threshold
Gladden et al.	Gas exchange threshold
Palka & Rogozinski	Respiratory anaerobic threshold

In order to determine lactate curve breakpoints, multiple scientific studies were conducted in practice. To exemplify, Sjödin & Jacobs (1981) used fixed lactate concentration in the blood of 4 mmol/L, Worms et al. (1985) applied 3 mmol/L., Hurley (1984) used 2.5 mmol/L, and LaFontaine et al. (1981) used 2.2 mmol/L. Using fixed values for the AnT determination increases the determination objectivity, on the one hand, but neglects individual differences of subjects, on the other, since a nonlinear increase of lactate concentration does not occur regularly at 4mmol/L (Williams et al., 1991). For determining AnT, tangent points to the lactate curve are used, so Simon et al. (1981) applied a 51° angle, and Keul et al. (1975) used 45°. According to the above, depending on units of measure along with relative values of X and Y scales, tangent points for particular angles show different AnT values, which renders the accuracy of the above AnT determination method questionable. Cheng et al. (1992) constructed the so-called D-max method by determining the maximal distance from the straight line connecting the beginning and end of the lactate curve at a 90° angle. This method of threshold determination is dependent on the initial value of exercise intensity, along with the maximal intensity level achieved in the test by an individual. In order to neutralize the effect of the initial exercise intensity, Bishop et al. (1998) connected an upper part of the curve with a curve point representing LT by means of which they discovered that this modified D-max method (D-mod) highly correlates with the 1h-long testing protocol for the determination of AnT in top female cyclists. For the values of the criteria for the definition of AnT, see Table 3.

Table 3. Criteria for the determination of AnT

Literature	Term	Criteria
Sjödin & Jacobs	OBLA	4 mmol/L
Kindermann et al.	Lactate threshold	2 mmol/L
Hughson et al.	Lactate threshold	0,5 mmol/L above level at rest
Hurley et al..	Lactate threshold	2,5 mmol/L
Worms et al.	Lactate threshold	3 mmol/L
Keul et al.	Individual AnT	(La^-) Tangent at 45º
Simon et al..	Individual AnT	(La^-) Tangent at 51º
LaFonaine et al.	Maximal stability state	2,2 mmol/L
Conconi et al.	Anaerobic threshold	Deflection points of heart frequency
Hugues et al.	Ventilatory threshold	Ventilation breakpoint
Snyder et al.	Maximal lactate stability state	% of maximal heart frequency
Holmann	Point of optimal VE efficiency	(VE) tangent at 45º
Davis et al.	Anaerobic threshold	VE/VO_2 increase but not VE/VCO_2
Jones et al.	Ventilatory threshold	VCO_2 breakpoint

OBLA = beginning of lactate accumulation; TDMA = threshold of non-compensated metabolic acidosis; VE = minute ventilation; VO2 = oxygen consumption; VCO2 = amount of eliminated CO2 per minute

Differences between methods for the determination of AnT gave rise to mistakes in the interpretation of testing results. Notwithstanding that there should be just one threshold value, the AnT values calculated using different scientific methods at the same data sample indicated variation in AnT values amounting to 79 - 92% of VO2max (Tomakidis, 1998). In any case, every shift of the lactate curve to the right, when expressed in terms of %VO2max, is a good indicator of improved aerobic endurance. The determined values of lactate concentration at the same work intensity were lower in subjects with smaller amounts of glycogen stored in muscles than those with higher quantities. Such an example implies that a curve shifts to the right or downward is potentially incorrectly interpreted as an aerobic endurance improvement. Such a phenomenon is accounted for in the accessible literature as the "lactate paradox" (Kayser, 1996).

Ventilatory threshold (VT)

Wasserman (1964) used the values of gas analyses and changes in ventilation markers in order to determine the so-called "ventilatory threshold." This noninvasive method draws on the hypothesis that hydrogen ions (H+) as constituent elements of lactic acid get metabolized by means of blood buffers, i.e., bicarbonates, while producing increased CO2 concentration that affects an increased minute ventilation (VE). According to this theory, an increased concentration of H+ in blood coincides with a hyperventilation increase during the testing protocol with a gradually increased workload. Even though a high number of publications reported results according to which VE correlates highly with lactate threshold (LT) (Aunola et al., 1986; Sucec et al., 1985; Davis et al., 1976; Burke et al., 1994), the validity of the above statement raises serious doubts. Firstly, and most importantly, by application of different techniques (Table 3), the significance of the correlation between ventilatory threshold and lactate threshold is not a strong enough criterion for the determination of validity. In their research using the cycle ergometer protocol, Hugues et al. (1982) (see Table 3) showed that lactate threshold and ventilatory threshold can be influenced independently of each other by changing the frequency of pedal rotation (LT< VT per 90 rpm, but not at 50 rpm), or based on the number of energy substrates (LT > VT in the stage of consumed glycogen reserves but not in the phase of the normal glycogen concentration). Adding to the abovementioned the facts that VT identification is highly individualized, that the determination of different threshold levels is possible with the same testing results (Yeh et al., 1983) using various methods and depending on the stage duration in the progressive workload test (Kang et al., 2001), the above studies indicate that the AnT determination during the progressive workload tests with noninvasive methods through ventilation parameters is questionable from the aspect of validity.

Determination of threshold based on the heart frequency values

Research by Wyndham et al. (1959) shows that the relationship between the heart frequency curve and work capacity during the test of progressive workload is sigmoidal, i.e., linear within the central part of the curve and that it reaches its plateau as the workload intensity approaches the maximal value. Conconi et al. (1982) found that the deflection point at the curve heart frequency work capacity is at the same level of work capacity as the deflection point of the curve La work capacity (Table 3). Authors suggested that the use of noninvasive on-site tests enables precise determination of the deflection point. Despite being widely used in the training practice of coaches and athletes, the Conconi test arouses sharp criticism in the professional literature (Thorland et al., 1984; Walker et al., 1995; Jones et al., 1997). Jeukendrup et al. (1997) explored the existence of the deflection point from a physiological aspect, and they found that it is an artifact being dependent, to a large extent, on the testing protocol. In order to overcome these methodological shortcomings, Conconi et al. (1996) modified the existing testing protocol by replacing a fixed distance stage with a fixed time length. Bourgois et al. (1998) applied the new modified testing protocol to the sample of top rowers in order to locate the deflection point. Using the modified test, the authors managed to determine the deflection point of each subject in the study. In their original research, Conconi et al. (1982) reported a considerably high relationship between the two variables, i.e., between the deflection of heart frequency and the deflection of LT (r = 0.99). Even though a group of authors proved the above relationship between the two variables (Droghetti et al., 1985; Cellini et al., 1986; Petit et al., 1997), a great many studies failed to determine a significant relationship (Tomakidis et al., 1998; Heck et al., 1985; Walker et al. 1995; Pokan et al., 1995; Jones et al., 1997). In their research, Jones et al. (1997) and Bourgois et al. (1998) found out that the modified Conconi test was not a valid instrument for the noninvasive determination of the AnT by reporting that the differences between deflection points on the curves work capacity heart frequency and work capacity lactate concentration ranged from 13% to 28%. Both studies have shown that continual exercising at an intensity determined based on the position of the deflection point yields significantly different lactate concentrations in the blood (8.1 ±1.8 and 10.4±3.10 mmol/L) as well as a rapid fatigue incidence (time to failure = 15.9 ±6.7 and 17.5 ± 11.1 min).

Practical considerations

The production of lactate during continual exercising, as described by Brooks (1985) in his research, depends on lactate metabolism in the heart and skeletal muscles, as well as in the liver. During continual exercising, increased lactate concentration in the blood is highly conditioned by exercise intensity (Scheen et al., 1981). Throughout low-intensity exercises, an increased quantity of lactate concentration in the blood occurs, as well as a short-lasting plateau and drop in concentration; but, during high-intensity exercise, lactate concentration gets constantly increased so as to reach its maximum before the end of the exercise. In practice, there is an exercise intensity at which lactate concentration increases progressively until it reaches a stable state. As per the definition, the represents the maximal exercise intensity during which the accumulation level of lactate in the blood and its degradation level is in balance (Brooks et al., 1985). Most researchers located maximal lactate steady state (MLSS) at 70% and 80% of VO2max (Hermansen et al., 1972; Ribeiro et al., 1986; Billat et al., 1994; Dekerle et al., 2001). On the sample of top rowers, Beneke reported that the exercise intensity level and lactate level at MLSS were lower maximal lactate steady state than 4 mmol/L values or the values of an individual AnT, based on which he concluded that the AnT does not represent MLSS in rowing (Beneke et al., 1995). In their research, Heck et al. (1985) found a high correlation between lactate concentration at 4 mmol/L and MLSS and also during the treadmill testing protocol, as well as during the testing protocol on the cycle ergometer. The Authors indicated that the speed at 4mmol/L was higher than that at MLSS when the stage of the progressive workload test lasted for 3 minutes; however, the same was not true when the stage lasted for 5 minutes. Thus, the authors concluded that a 4 mmol/L concentration could be significant for the determination of MLSS only when the stage of the progressive workload test lasts for 5 minutes. Jones et al. (1997) found a high correlation between 4 mmol/L concentration and MLSS in the sample of highly trained runners, provided that the 4 mmol/L value was higher than the MLSS value when the stage lasted for 3 minutes. On the sample of top runners and cyclists, Urhausen et al. (1993) found that constant workload at the level of an individual aerobic threshold corresponds to the stable lactate state; however, a 5% intensity increase leads to a continual increase in lactate concentration in the blood. The determination of MLSS is based on the test of continual workload lasting for 30 minutes in total, at the intensity of 50% to 90% of VO2max (Beneke, 1995; Scheen et al., 1981; Urhausen et al., 1993). The above testing protocols aimed to determine the maximal exercise intensity during which no significant increase of lactate concentration in the blood would occur, in the amount of 1.0 mmol/L between 10 and 30 minutes (Snyder, 1984). In their research, Billat et al. (1994) showed that MLSS could be determined based on two continual protocols lasting for 20 minutes at intensities of 65% and 80% of VO2max with 40 minutes of intermission between the two. Differences in values of lactate concentration between 5 and 20 minutes, in each and every repetition, can be illustrated graphically in relation to the speed of movement. The method is simple and practically applicable, but its validity is questionable since this protocol builds on the hypothesis that there is a linear relationship between lactate accumulation and work capacity. Hughson et al. (1987) and Oyono-Enguelle et al. (1990), showed that the relationship between lactate accumulation and work capacity is described more precisely with an exponential curve. According to the research by Billat et al. (1994), such a nonlinear relationship between lactate concentration and work capacity can be controlled using testing protocols for two speeds of similar intensity. In this way, the exponential arc on the lactate curve will be transformed into a straight line, by means of which the chance of incorrect MLSS evaluation through the interpolation procedure is reduced to a minimum. As early as 1979, Davis et al. constructed a test they named as "lactate-minimum test" (LMT) with an aim to determine MLSS precisely using only one test. The LMT is a test with a gradual workload applied immediately after a supra-maximal intensity during which lactate concentration reaches high values (8 > mmol/L). After a short break following the end of the supramaximal exercise, the LMT gets administered. At intensities lower than MLSS, the lactate removal level exceeds its accumulation level; however, at the ones higher than MLSS, the accumulation level exceeds its removal level, which results in an increased lactate concentration in the blood. Lower lactate concentration values are brought to the relationship with MLSS values, and the performance speed is represented as lactate minimal speed (LMS). Due to the standardization failure of the above procedure in the accessible literature, the LMT procedure is open to criticism (Jones & Doust, 1997; Carter et al., 1999). Following the supramaximal workload, lactate concentration in the blood should be sufficiently high, but it must not cause overfatigue before starting the LMT protocol. Carter et al. (1999) proposed lactate concentration levels of 8 mmol/L, along with a long enough recovery and LMT test stage to establish a balance between lactate accumulation and removal.

According to research results in the accessible scientific literature, the AnT shows a significant relationship with various types of endurance so it is accounted for as a better success indicator than the VO2max in long-distance running events (Moritani & DeVries, 1979; Yoshida et al., 1981). Even though ample experimental research findings confirm the validity of the AnT concept, the results of particular studies raise doubts about its validity. Expressed in different units of measure (m/min, km/h, ml/kg/min), the AnT does not stand for the extent of aerobic endurance only, but it also represents the extent of VO2max and mechanical efficiency, i.e., the higher the VO2max level, the higher the AnT expressed as ml/kg/min. Should we wish to estimate the level of aerobic endurance only based on the AnT, then AnT should be expressed as %VO2max since the AnT expressed in percentage of maximum oxygen consumption is a better predictor of success than the VO2max alone (Palgi et al., 1984). For the improvement in middle-distance and long-distance races, Holmann et al. (1981) proposed that training intensity should be determined and prescribed based on the AnT values rather than VO2max and maximal heart frequency rate. The research results indicate that the application of exercise intensity at the AnT level causes rightward movement of the lactate curve, which implies improved AnT values along with values of VO2max and % VO2max. The findings of a meta-analysis of 34 various studies and 85 experimental groups suggest a conclusion that AnT-based training intensity is a sufficiently strong stimulus for AnT level improvement in non-trained persons (Londeree, 1997). The level of training stimuli for improved AnT and VO2max depends, to a great extent, on individual levels of aerobic abilities, so it is impossible to draw a conclusion that AnT-based training is a sufficient stimulus to affect changes in the endurance of top long-term runners.

Limitation of the study

The limiting factor of this study is reflected in the fact that currently in scientific practice new methods of determining the anaerobic threshold using Near infrared spectroscopy (NIRS) are used, while in this study methods of determining the anaerobic threshold based on lactate measurement are used. concentration and gas exchange are treated. Further research is necessary to determine the effectiveness of these new methods for determining anaerobic threshold levels based on NIRS technology, as well as their practical applicability.

Conclusion

In relation to the validity of the methods for assessing aerobic endurance that were established at the end of the 20th century, and their practical application in the training process, especially in endurance sports,, we may conclude that the training intensity based on the AnT only does not represent a proper stimulus for increased endurance of long-distance running athletes, even though it may be a highly useful marker for monitoring and evaluating training programs intended for endurance improvement. Terms related to AnT-related should be excluded from official use since scientists and trainers focus on the arbitrary interpretation of the lactate curve (at the particular %VO2max) to determine whether an improvement has occurred or not based on the curve shift rightward or leftward. That would reduce to a minimum all effects of the AnT or speculations on its validity, and the analysis of the lactate curve shift alone would enable better-quality prediction of results in endurance sports (long-term racing events).

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