Alqalam Journal of Medical and Applied Sciences. 2025;8(1):251-257
https://doi.org/10.54361/ajmas.258138

Original article

Maximal Oxygen Uptake and Lactate Threshold in Anaerobic Exercise: A Sub-Athletic Case Study

Masoud Kahmasi

Department of Rehabilitation and Physiotherapy, Faculty of Physical Education and Sport Sciences, Tripoli University-Libya

Corresponding Email. mrlibyankahmasi@gmail.com

Abstract

This case study was aimed to study and establish the physiological variables caused by incremental endurance training of one sub-athletic male subject. It was designed to test the lactate threshold [LT], economy and maximal oxygen uptake ($VO_{2max.}$) throughout two distinct parts of incremental endurance exercise using cycling ergometer. in contrast to the main hypothesis that was suggesting; the lactate threshold, the point of sudden rise in blood (systemic) lactate during incremental endurance exercise will have a fatiguing effect on performance and would not allow researcher to ascertaining a true $VO_{2\ max.}$ However, the main results indicated lactate threshold [LT] taken place at work rate of 120 (w) represents 66.5% of maximum subject's heart rate, obviously it did not affect the true $VO_{2\ max.}$ result. So, a combination of factors may explain the variation of lactate threshold. Or rather, that lactate does accumulate as [LT] has variable effects on the outcome of subject's endurance performance. That is to say, the uneconomical increase in power expenditure (economy), in addition to other metabolic determinants.

Keywords: Incremental Test, Cycling Economy, Blood Lactate, Maximum Heart Rate, Work Rate.

Introduction

Lactate threshold is a common term used to explain the point of sudden rise in blood (systemic) lactate during incremental exercise [1]. However, an increase evidences that suggest not only the lactate threshold but also the exercise economy - an energy cost (VO_2) of sub maximal exercise- are important determinants of an individual potential in endurance exercise [2]. It has been reported a limitation in the ability of human beings to improve their maximal oxygen uptake of endurance performance [3]. Alternatively, the $VO_{2max.}$ has traditionally been considered to be the most significant cardiovascular measure of nonathletic individual potential in endurance exercise [4]. VO_{2max} in addition to the other measures were used to provide a comprehensive image of adaptations in the physiology of the endurance training. These adaptations improved the work rate estimated to be associated with $VO_{2max.}$, and resulted in improved the incremental exercise performance.

This laboratory case study primarily derived from procedure described by Björkman, 2017 [5], cycling ergometer has been used. The test is involved two distinct parts in order to assess the three main components that affect performance of endurance exercise; economy, lactate threshold and $V0_{2max.}$ on a male subject. During first part; an incremental 'steady state' exercise test was performed to assess both of lactate threshold and exercise economy. The second part was immediately continued after the lactate threshold test – is a shorter incremental test to determine the final minute of averaging $VO_{2max.}$ linked-data. However, the higher VO_2 of less skilled cyclists at blood lactate concentration of 4mmol.l-1 suggest that they are likely to fatigue earlier than elite ones. A possible explanation for this fatigue is an H+ accumulation and decrease in intracellular PH resulting from glycolysis; both are interfering with the actin and myosin interaction, and then a reduction in force production [6].

The aim of this study was showing the result measurements in relation to lactate threshold, economy and $VO_{2max.}$ throughout the cyclic endurance exercise. Hence, it's related report will describe the possible association between these three determinants with references to the previous concerned studies.

Methods

Participant

An academic graduated student 25 years old male from Higher Institute of Science and Technology / Qasr Bin Ghashir - Tripoli Libya, volunteered to participate in the experiments, who is according to (7) physically defined as sub-elite level "who want to become elite but are not quite there yet". His height: 179 cm and weight: 69 kg, BMI: 21.5Kg/m^2. Also, his training status of isotonic exercise is limited with some endurance workout and lack of regular cycling but well treadmill experience. However, the test has been done in Ali Omar Askar Hospital Physiotherapy Department the hole temperature was 24°C and their relative humidity was 34% under Baro-pressure of 738 mmHg.

Protocol

An ergometric bicycle (DMS) was used for all steps of experiment. An initial work rate of 70 watts (W) and maintaining 70 revolutions per minute (rpm) have been applied when the test start, and then increased by

Received*: 00-00-2025 -* ***Accepted****: 00-00-2025 -* ***Published****: 02-01-2025*

25 W throughout the incremental stages. The first part of the test involved [5] incremental stages with each stage lasting for 4 minutes. The following components had been taken at the end of each stage; lactate, work rate, heart rate, rate of perceived exertion (RPE), VO_2, and respiratory exchange ratio (RER). When an increase of significance was recorded in blood lactate, that is to say, lactate threshold [LT ≈ 5 mmol.l^{-1}] the second part of the test was started. So that the work rate was incrementally increased every one minute by 25 W in order to demonstrate $V0_{2max.}$ However, when the subject had felt exhaustion and could no longer continue the test was stopped, he was monitored until felt comfortable. The instruments were already removed.

Physiological measurements

An ergo-spirometer-Vo2 $_{max}$ Finder; via collection of expired air (breath x breath) 15 second at end of each stage; hence it needs to switch on for worm up and calibration. The subject was fitted with the relevant equipment; gas analysis, mouth piece, heart rate monitor, nose clip.

Lactate profile – Lactate strip, a blood samples were taken from the tip of fingers applying alcohol swap. Lactate threshold analysis [LT] – Work Rate (W) and VO_2 were determined at the lactate threshold and a blood lactate concentration of ≈ 5 mmol.l^{-1}. Blood lactate concentrations were plotted against power at which they were produced and line of best fit from the predetermined lactate threshold to intercept with the blood lactate values on the two lines. From these points, lines were perpendicular drown down to the horizontal axis to obtain the physiological variables. Data collected on January 2nd of 2017. Computer excel sheet was used for data record, and then a mathematical regression analysis was applied to model the lactate data, VO_2 and work rate (Table 1.0).

Results and Discussion

This physiological case study is aimed to evaluate firstly the point of lactate threshold, secondly the $VO_{2\ max}$, and thirdly the economy of an endurance exercise. In general, these essentials are known to be important determinant of endurance performance [8]. In 1990, Weltman and colleague verified this incremental exercise test, who designed a simple and valid method to demonstrate the lactate threshold and $VO_{2\ max.}$(9). Accordingly, the blood lactate test and VO_2 results obtained throughout this test should not be influenced in terms of experimental validity.

Kenney et al. (2022) have defined the lactate threshold the point at which blood lactate begins to accumulate above resting level during exercise of increasing intensity [10]. Therefore, this experiment is depended on a multi-stage test protocol (table 1) with frequent stages and duration of 4 minutes (part 1). Hence, we ensure optimum results with simplicity and good validity of the outcome. During part 1 the blood lactate concentrations are clearly increased specially after stage 2 of this laboratory test. However, in biochemistry it is known the anaerobic metabolism in muscles where the lactate is being produced as is removed from the blood by liver and heart. Alternatively, the rate of lactate removal from the blood might increase as higher as the rate of production at the beginning of test [10]. In addition to that the work rate (W) could also be too low for the subject's work rate.

Table 1. The measurements and results of each part of the test. These are highlighted after stage 5; part two of the assessments started.

Stages	1	2	3	4	5	6	7	8	9
Heart Rate bpm	112	126	141	144	156	163	167	173	180
Work Rate (watts)	70	95	120	145	170	195	220	245	270
La mmole.l-1	1.8	1.6	2.6	3.5	5.4	-	-	-	-
RPE	9	10	11	12	14	-	-	-	-
VO2 ml.min-1.kg-1	17.89	20.36	24.04	26.76	32.1	33.32	34.60	38.00	38.95
RER	0.8	0.94	0.95	0.99	1.07	1.13	1.18	1.20	1.26

According to figure 1; the [La] in relation to heart rate shows that at the point of [LT] heart rate was 130 bpm which represents 66.5% of maximum subject's heart rate. It is clear from the first five stages that the heart rate seems to be little increased, especially at the region of [LT]. For this reason, the [La] does not behave as a limiting factor on heart rate. Despite that Brooks (2001) has made a question mark about the fatigue effect of lactate; in this test the subject has reached the point of exhaustion(11). However, he did not try to get his maximum heart rate at onset of lactate accumulation, this might be validated by the results of Hoogeven and Hoogsteen (1999) who argued in their experiments that lactate threshold is likely to respond to 65%-85% of $HR_{max.}$, this result is correlated with the subject's heart rate value (66.5%). Therefore, the acidosis caused by lactate and accumulation of hydrogen ions is likely the cause of fatigue even though the heart rate is not a limiting factor at [LT] [12]. Moreover Tjelta Enoksen (2010) concluded that a relatively

Received*: 00-00-2025 -* ***Accepted****: 00-00-2025 -* ***Published****: 02-01-2025*

aerobics with low intensity (62-82% of HR max) added to training close to the anaerobic threshold (82-92% of HR_{max}) was leading reason to development an improvement in VO2max and running performance [13].

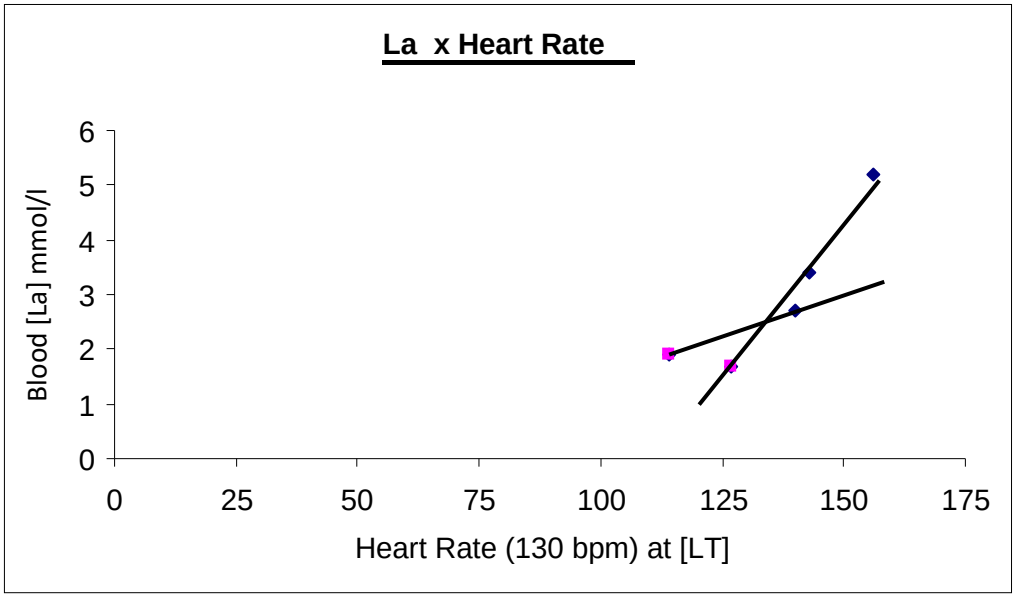

Figure 1. The relationship between blood lactate concentrations and heart rate at each stage. The intersection of the two lines indicates the lactate threshold in relation to heart rate.

Figure 2 indicate that lactate threshold occurred at a work rate of 120 W and according to the best fit point of the two lines, the [LT] was 2.6 $mmol.l^{-1}$. In the same way, there were two studies conducted by Lucia et al. (1998) and Harnish et al. (2001), both of these studies have identified the substantial increase of lactate [La] levels in the blood in the region of 2.5 $mmol.l^{-1}$ [14,15]. Although both of these studies have applied on athletes at higher exercise intensity (work rate) level, the subject's lactate threshold [LT] of 2.6 $mmol.l^{-1}$ seems to be an acceptable level of sub-athletics. However, a combination of factors may explain the variation of lactate threshold; (1) reduced muscle oxygen, (2) increased metabolic glycolysis, (3) fast-switch muscle recruitment, (4) decreased rate of lactate removal [8].

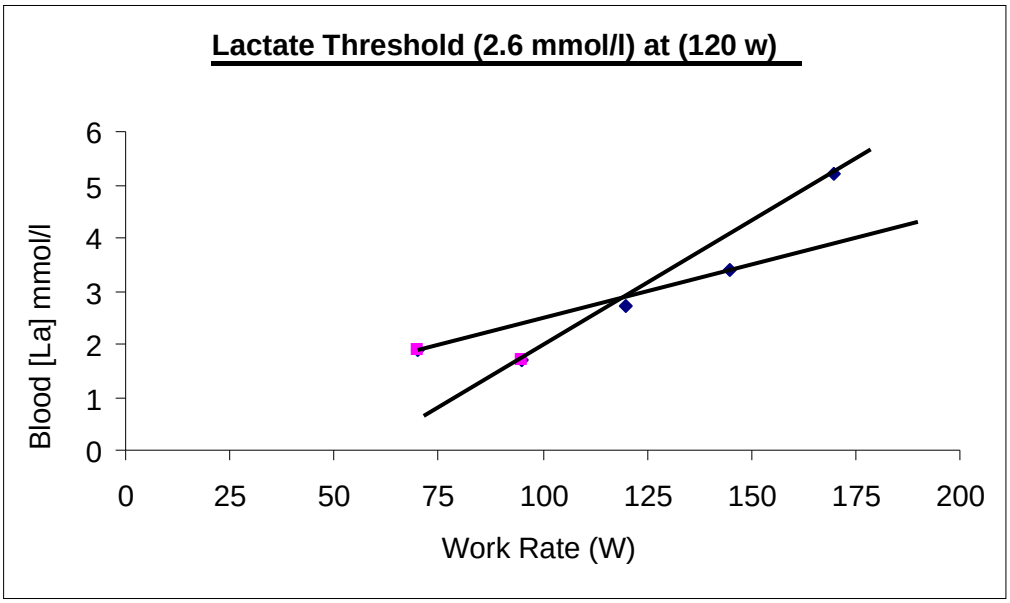

Figure 2. The concentrations of lactate [La] across work rate (w) during an incremental exercise test (part 1).

According to results at table 1; the relationship between [La] and VO_2 is demonstrated by figure 3 – the lactate threshold of this subject occurred at 22 $ml.min^{-1}.kg^{-1}$, and then its level is 55% of $VO_{2\ max}$. With regard to the studies conducted by Jones (1998) on highly trained athletes, lactate threshold has occurred at an intensity of 88 % of $VO_{2\ max}$., depended mainly on the performance ability of subjects. In other study done by Amann et al., (2006) using also a group of experienced cyclists, so that they found [LT] in the range

Received*: 00-00-2025 -* ***Accepted****: 00-00-2025 -* ***Published****: 02-01-2025*

of 57-92% of $VO_{2\ max}$. However, there is a wide range of $VO_{2\ max}$ where [LT] is likely to occur. They concluded that in general, ventilatory threshold VT superior to LT variables and the simplest of several valid measures appears to be VE/VO_2. Their experimental group respiratory exchange ratio RER = 1 and 0.95 being consist with the study subject RER = 1.07 and 0.95 at [LT] (Tabel 1.0) [16]. With regard to our subject in this laboratory test who sub-athletic involved in limited exercise performance and lack of cycling experiences, as well as the untrained cardio-respiratory system and reduced muscle strength. For these reasons, his [LT] is likely to be at a much lower level against $VO_{2max.}$ in despite of the valid result of lactate threshold.

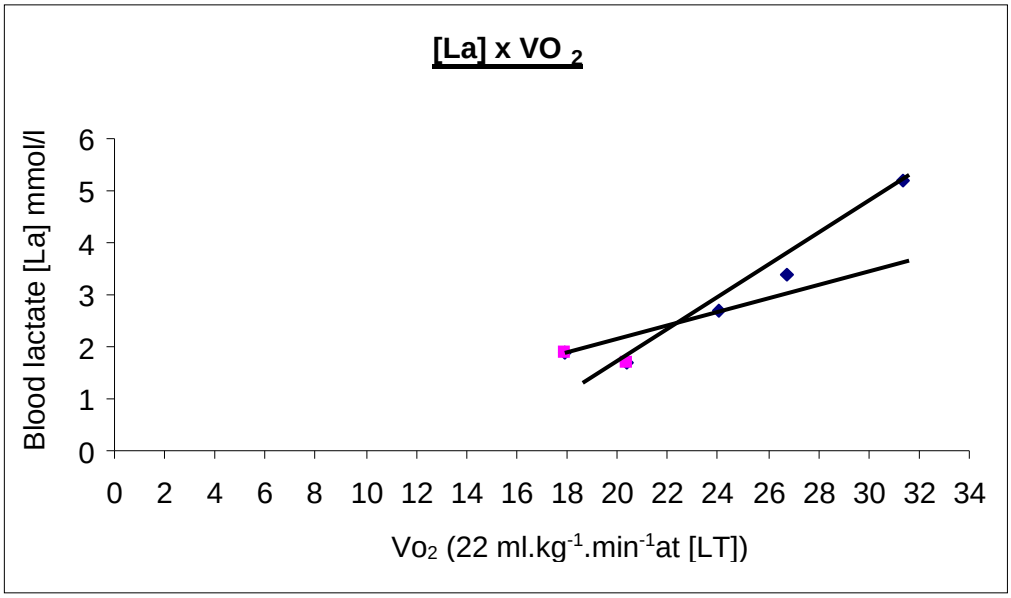

Figure 3. The relationship between blood lactate and VO2. At 22.5 ml.kg-1.min-1 lactate threshold could be recognised at 55 % of the VO2max.

Tanaka's formula [208 – 0.7 × age] is assigned to predicted maximum heart rate HR_{Max} at the end of test should typically be [208 – 0.7 × 25 = 196 bpm [17]. A subject's HR_{Max} [180 bpm] in fact, did not reach 196 bpm; this could indicate to an exhaustion and development of muscle fatigue in addition to lack of subject's experience. According to Powers & Howley (2001) the most useful determinants of athlete's potential performance is VO2 max., lactate threshold as well as economy of movement [8]. Whereas the subject is going to be uneconomical; expend a great amount of energy and the O_2 requirement is expected to be high, this could be demonstrated in figure 4 – with results particularly during part 2 showing $VO_{2max.}$ is being rapidly reached and then there was increase in power expenditure.

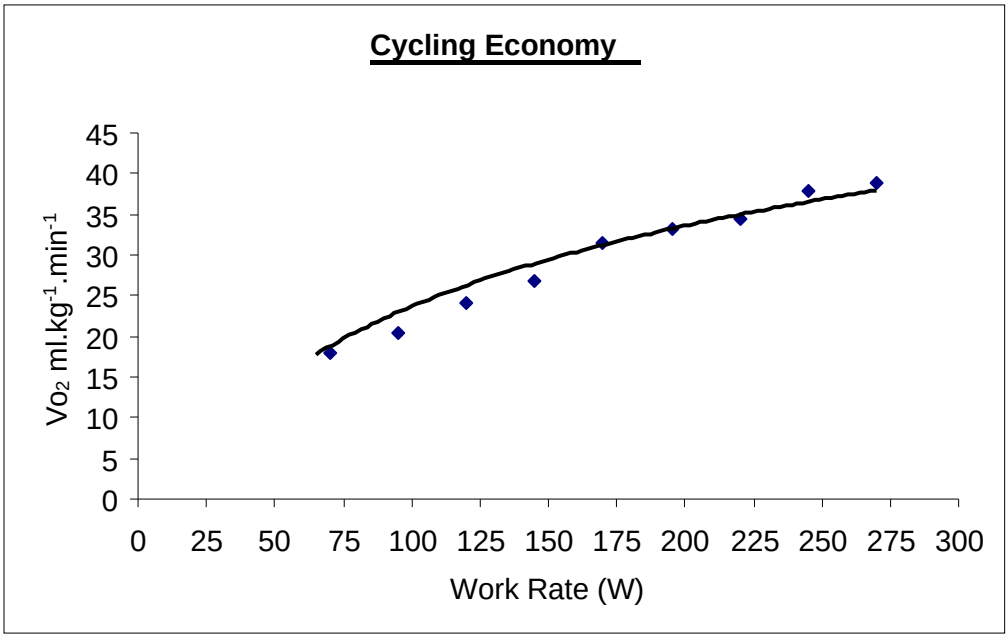

Figure 4. The relationship between work rate and VO2 in terms of cycling economy at each stage.

Received*: 00-00-2025 -* ***Accepted****: 00-00-2025 -* ***Published****: 02-01-2025*

Rating of perceived exertion (RPE) was at [11], according to Borg scales, which means (very light to fairly light) grade of the subject's perceived exertion revealed at lactate threshold. However, this grade is good indicator of the subject's effort in terms of heart rate max. (66.5%) to reflect the intensity of exercise to be moderate at rating between 12-13 [10]. RPE obtained by the Borg scale may be a superior differentiator of the blood lactate response to anaerobic exercise [18]. Therefore, the [LT] could not be correlated with the RPE (Figure 5).

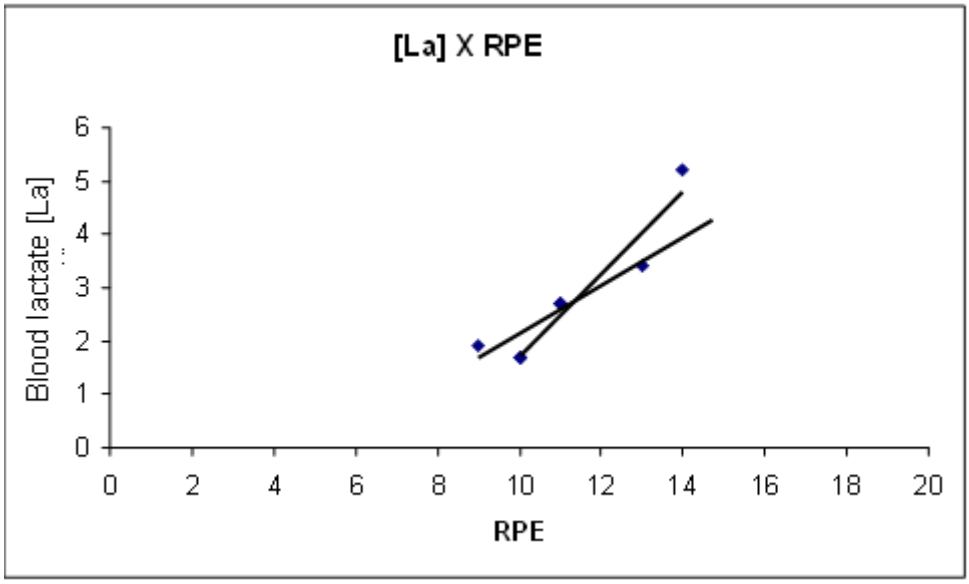

Figure 5. Rating of perceived exertion (RPE) intersect with [LT] 2.6 mmol/l was at [11].

There is another reference point which known as the onset of blood lactate accumulation. Because there is a considerable controversy (19) about the relationship of [LT] and anaerobic metabolism (glycolysis); in 2022, Kenney et al. have questioned the role of anaerobic working system to elicit lactate threshold, they concluded that most people are able to elicit lactate concentration at limited variable mmols.l^{-1} during incremental test (10). This concentration is referring to onset of blood lactate accumulation 'OBLA'. OBLA is mainly used with elite and it should in average value between 3.0-5.6 mmol.l^{-1} (20), whereas (10) have pointed out an arbitrary value of OBLA to be 2.0 or 4.0 mmol.l^{-1}. However, the highest [LT] or 'OBLA' will reflect the best endurance performance, so it might be acceptable to find the subject's OBLA at 3.5 mmol.l^{-1} as another standard point of reference (Figure 6).

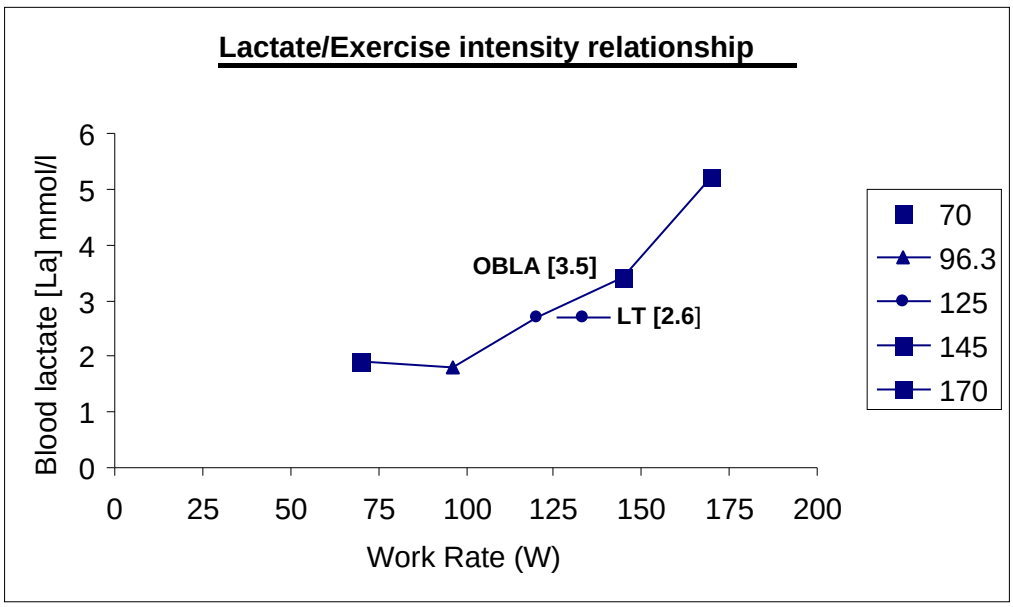

Figure 6. The highest [LT] and 'OBLA' at 2.6 and 3.5 mmol.l- respectively, reflecting the best subject's endurance performance.

In practical meaning, the cause of quick fatigue could result in the occurrence of early lactate threshold [1.8] at a relative low work rate in addition to the figures of RPE, heart rate and underline metabolic by-products

Received*: 00-00-2025 -* ***Accepted****: 00-00-2025 -* ***Published****: 02-01-2025*

e.g. K^+, H^+, CO_2, HCO_3^- (11) and (21). Moreover, the outside factors like; motivation, heat, humidity, attitude [8] are usually affecting the outcome of subject's performance.

Conclusion

This case study - laboratory test - was aimed to determine the most common component of exercise endurance, these are included the lactate threshold [LT], $VO_{2max.}$ and cycling economy. The data which have been recorded could reveal to valid results. However, the subject is uneconomical as he was quickly exhausted and lactate threshold [LT] has been reached in part 1 of the test, $VO_{2\ max.}$ was achieved during part 2 as plateau. The greatly increase of blood [La] throughout the stages appear to be reasonable factor affecting the performance of subject in terms of $VO_{2max.}$, RPE, work rate, and cycling economy.

Acknowledgments

It is my pleasure to acknowledge the administration team of Ali Omar Askar Hospital - Espiaa -Tripoli, and a lot of thanks for the Department of Rehabilitation and Physiotherapy PESS- University of Tripoli that have supporting and motivating given a technical support (e.g., materials used for experiments).

Conflicts of Interest

No conflicts of interest

References

1. Ghosh AK. Anaerobic threshold: its concept and role in endurance sport. Malays J Med Sci. 2004 Jan;11(1):24-36.
2. van der Zwaard S, Brocherie F, Jaspers RT. Under the Hood: Skeletal Muscle Determinants of Endurance Performance. Front Sports Act Living. 2021;3(August):1–11.
3. Bassett DRJ, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc. 2000 Jan;32(1):70–84.
4. Srivastava S, Tamrakar S, Nallathambi N, Vrindavanam SA, Prasad R, Kothari R. Assessment of Maximal Oxygen Uptake (VO2 Max) in Athletes and Nonathletes Assessed in Sports Physiology Laboratory. Cureus. 2024 May;16(5):e61124.
5. Björkman F. Validity and Realidity of a Submaximal Cycle Ergometer Test for Estimation of Maximal Oxygen Uptake. 2017;1–126.
6. Cosgrove MJ, Wilson J, Watt D, Grant SF. The relationship between selected physiological variables of rowers and rowing performance as determined by a 2000 m ergometer test. J Sports Sci. 1999 Nov;17(11):845–52.
7. Lorenz DS, Reiman MP, Lehecka BJ, Naylor A. What performance characteristics determine elite versus nonelite athletes in the same sport? Sports Health. 2013 Nov;5(6):542–7.
8. Powers S, Howley E. Exercise Physiology. USA: Von Hoffman Press; McGraw-Hill Companies.; 2001. 51–54; 390–399 p.
9. Weltman A, Snead D, Stein P, Seip R, Schurrer R, Rutt R, et al. Reliability and validity of a continuous incremental treadmill protocol for the determination of lactate threshold, fixed blood lactate concentrations, and VO2max. Int J Sports Med. 1990 Feb;11(1):26–32.
10. Kenney WL, Wilmore JH, Costill DL. Physiology of sport and exercise. Human kinetics; 2022.
11. Brooks GA. Lactate doesn't necessarily cause fatigue: why are we surprised? J Physiol. 2001;536(Pt 1):1.
12. Hoogeveen AR, Hoogsteen GS. The ventilatory threshold, heart rate, and endurance performance: relationships in elite cyclists. Int J Sports Med. 1999 Feb;20(2):114–7.
13. Tjelta LI, Enoksen E. Training characteristics of male junior cross country and track runners on European top level. Int J Sports Sci Coach. 2010;5(2):193–203.
14. Lucía A, Pardo J, Durántez A, Hoyos J, Chicharro JL. Physiological differences between professional and elite road cyclists. Int J Sports Med. 1998 Jul;19(5):342–8.
15. Harnish CR, Swensen TC, Pate RR. Methods for estimating the maximal lactate steady state in trained cyclists. Med Sci Sports Exerc. 2001;33(6):1052–5.
16. Amann M, Subudhi AW, Foster C. Predictive validity of ventilatory and lactate thresholds for cycling time trial performance. Scand J Med Sci Sports. 2006;16(1):27–34.
17. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001 Jan;37(1):153–6.
18. Irving BA, Rutkowski J, Brock DW, Davis CK, Barrett EJ, Gaesser GA, et al. Comparison of Borg- and OMNI-RPE as markers of the blood lactate response to exercise. Med Sci Sports Exerc. 2006 Jul;38(7):1348–52.
19. Gerard MP, Graaf-Roelfsema E de, Hodgson DR, Van Der Kolk JH. Energetic considerations of exercise. The Athletic Horse: Principles and Practice of Equine Sports Medicine: Second Edition. 2014 Jan 1;19–33.
20. Bovell DL, Nimmo MA, Wood L. Principles of physiology: A scientific basis of physiotherapy. WB Saunders; 1996.
21. Bentley DJ, McNaughton LR. Comparison of W(peak), VO2(peak) and the ventilation threshold from two different incremental exercise tests: relationship to endurance performance. J Sci Med Sport. 2003 Dec;6(4):422–35.

Received*: 00-00-2025 -* ***Accepted****: 00-00-2025 -* ***Published****: 02-01-2025*

https://doi.org/10.54361/ajmas.258138

المستخلص

هذه دراسة حالة تهدف إلى دراسة وتحديد المتغيرات الفسيولوجية الناجمة عن تمرين التحميل المتزايد، لرياضي ثانوي متطوع موضوع البحث من الذكور. لقد تم تصميم التمرين لاختبار عتبة حمض اللاكتيك، وأقتصاد الطاقة، والحد الأقصى لإستهلاك الأكسجين (VO_{2max}) خلال جزأين متميزين من تمرين التحميل المتزايد باستخدام دراجة مقياس الجهد. وعلى عكس الفرضية الرئيسية التي كانت تقترح أن عتبة اللاكتات هي نقطة الزيادة المفاجئة لحمض اللاكتيت في الدم (الدورة الدموية)، أثناء تمرين التحميل المتزايد سيكون لها تأثير التعب على الأداء، وبالتالي لن تسمح للباحث بالتأكد من قيمة VO_{2max} الحقيقية. فمن ناحية أخرى، أشارت النتائج الرئيسية إلى أن عتبة اللاكتات التي حدثت عند معدل جهد قدره 120 (وات) تمثل 66.5% من الحد الأقصى لمعدل ضربات قلب الشخص موضوع البحث، ومن الواضح أنها لم تؤثر على الحد الأقصى الحقيقي لـ VO_2. نتيجة لذلك فإن هناك مجموعة من العوامل قد تفسر اختلاف عتبة اللاكتات. أو بمعني آخر حدوث تراكم فعلي للاكتات، لأن عتبة اللاكتيت لها تأثيرات متغايرة على نتائج أداء التحمل لدى الشخص المستهدف بالاختبار. ويمكن القول أن الزيادة غير الاقتصادية في استهلاك الطاقة، بالإضافة إلى المحددات الأيضية الأخرى لها دور في ذلك.

Received*: 00-00-2025 -* ***Accepted****: 00-00-2025 -* ***Published****: 02-01-2025*