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Comparison of Ventilatory and Blood Lactate Thresholds in Elite Soccer Players

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Abstract

Despite a long research history, the lactate threshold continues to be a widely controversial field. Notwithstanding the controversies and influence of multiple determinants, the estimation of lactate threshold in sports has been considered one of the essential parameters in the prescription of training intensity, load monitoring, and performance prediction. The study aimed to compare the anaerobic ventilatory and lactate thresholds as determined by different methods in elite soccer players. The study consisted of twenty-five division 1 elite soccer players. The players were separated into two groups based on their run times on the treadmill. Group 1 (age 24.38±7.33 years, height 180.33±7.03 cm, weight 75.53±7.68 kg) consisted of players who completed more than 17 minutes on the treadmill, while group 2 (age 25.11±6.07 years, height 182.11±10.03 cm, weight 79.72±7.54 kg) consisted of those who completed less than 17 minutes. The players completed an incremental maximal cardiopulmonary exercise testing from which ventilatory thresholds were determined. Furthermore, measurements of blood samples were obtained every 3 minutes after completing each stage of the test, with a total of 141 measurements completed. Multivariate tests indicated no significant differences in the speeds calculated with ventilatory and lactate threshold methods. These findings suggest that the anaerobic ventilatory threshold (VT2) can be used as an alternative to the invasive lactate threshold measurements. Therefore, identifying a threshold point without utilizing an invasive procedure enhances the potential application of the VT2 or respiratory compensation point.

Keywords: *Respiratory compensation, visual inspection, logarithmic transformations, maximum distance method, fixed blood lactate*

Introduction

Soccer is classified as a high-intensity intermittent team sport (Bradley et al., 2009) that requires high levels of cardiovascular fitness, strength, and power (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005). Elite soccer players cover about 10 km in 90 minutes during competitive games, with a mean intensity of about 75% of maximal oxygen uptake (VO2max) (Bangsbo, Mohr, & Krustrup, 2006).). Research demonstrated that low-intensity activity accounted for 85.4% of the total game time, while high intensity running and sprinting accounted for 6.4% and 0.6% of the total game time, respectively (Bradley et al., 2009). Researchers have suggested that distances covered during high-intensity running are indicative of physical performance in soccer due to their relationship with training status (Krustrup et al., 2005). Furthermore, research demonstrated a noteworthy contribution of the aerobic energy system during soccer games and a considerable stimulation of the anaerobic energy system as indicated by the high blood lactate concentrations (Krustrup et al., 2003). Consequently, variables such as VO2max, ventilatory threshold (VT), lactate threshold (LT), and blood lactate values are essential measurements for soccer players.

During an incremental exercise activity, an increase in load results in increased energy demands that derive from an immediate energy supply through the anaerobic glycolytic system (Hargreaves & Spriet, 2020). This results in the continuous

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production of lactate (lactate appearance in the blood) accompanied by increased lactate clearance (disappearance from the blood) by various lactate shuttling mechanisms (Hargreaves & Spriet, 2020). As the intensity of exercise increases, the rate of conversion of pyruvate to lactate increases rapidly as opposed to the rate of clearance (Karlsson & Jacobs, 1982). As a result, there is a disproportionate nonlinear increase in blood lactate accumulation, termed as the onset of blood lactate accumulation (Karlsson & Jacobs, 1982). During incremental exercise testing, the first lactate breakpoint in low intensity is known as the aerobic threshold (LT1), while the second rise in blood lactate is known as the anaerobic threshold (LT2). Identifying LT aids not only in the evaluation of performance but also in the prescription of exercise training intensities. Additionally, it has been proposed that the LT reflects the training status of elite soccer players and, therefore, can be used for the routine assessment of aerobic fitness in soccer players (Ziogas, Patras, Stergiou, & Georgoulis, 2011). Evidently, running performance in sports that heavily depend on an aerobic component, such as soccer, is not only associated with high levels of VO2max but also with other performance indices such as LT and its associated running velocities (Ziogas et al., 2011; Marcos, Koulla, & Anthos, 2018).

Incremental exercise testing is a common procedure for determining those physiological characteristics. Several methods have been proposed to determine LT over the years, among which the cut-off point of 4 mmol/l of blood lactate concentration (Kindermann, Simon, & Keul, 1979), the visual inspection (VI) (Davis Rozenek, DeCicco, Carizzi, & Pham 2007), the utilization of logarithmic transformations (Log-log T) (Beaver, Wasserman, & Whipp, 1985), and the various curve fitting procedures such as the maximum distance (DMax) method (Newell et al., 2007). However, no generally accepted fitting procedure has been established for LT assessments in professional soccer players as LT can be influenced by several factors, including the different testing modalities and methods. Additionally, although the LT methods are commonly used to set up individual training intensities, the relationship between lactate-based parameters and ventilatory thresholds (VTs) is still unclear. In VT1, the VO2 and carbon dioxide production increase proportionally, while HCO3- acts to buffer the lactic acid concentration in blood (Cerezuela-Espejo, Courel-Ibáñez, Morán-Navarro, Martínez-Cava, & Pallarés, 1992), while in VT2, the failure of bicarbonate buffering and the consecutive fall in blood pH result in blood lactate accumulation to rise considerably (Meyer, Faude, Scharhag, Urhausen, & Kindermann, 2004). A recent investigation indicated that ventilatory thresholds (VT1 and VT2) could be effective in setting up individual exercise intensity programs for endurance sports considering the individual metabolic responses (Wolpern, Burgos, Janot, & Dalleck, 2015). Interestingly, research on cyclists demonstrated that lactate threshold tests could be a valid and reliable alternative to ventilatory thresholds to identify the body's workloads when switching from aerobic to anaerobic metabolism (Pallarés, Morán-Navarro, Ortega, Fernández-Elías, & Mora-Rodriguez, 2016). More specifically, high reliability and validity were indicated between VT1 and LT as well as between VT2 and LT +2 mMol·L−1 (Pallarés et al., 2016). An additional study on runners and triathletes indicated that LT and LT+3.0 mMol·L−1 were solid predictors of VT1 and VT2, respectively (Cerezuela-Espejo, Courel-Ibáñez, Morán-Navarro, Martínez-Cava, & Pallarés, 2008). The aforementioned studies suggested that gas exchange systems require expensive equipment and laboratory conditions that may not be available to different teams or athletes. Nevertheless, VT2 remains an important physiological parameter to indicate the training intensity.

While some studies examined the relationship between ventilatory and lactate exercise performance parameters in running and cycling, no previous studies examined whether the ventilatory threshold (VT2) can be used as an alternative to the invasive LT measurements in elite soccer players. Thus, this study aims to compare the ventilatory (VT2) and lactate thresholds as determined by different methods (VI, Dmax, modified Dmax, Log-log, and lactate at 4 mmol/l) in elite soccer players utilizing the modified Heck incremental maximal exercise protocol.

Methods

Participants

The study consisted of twenty-five division 1 elite soccer players (age 24.64±6.78 years, height 180.98±8.07 cm, weight 77.04±7.75 kg). The players were separated into two groups based on their treadmill run times (RT). Group 1 consisted of players (n=16, age 24.38±7.33 years, height 180.34±7.03 cm, weight 75.53±7.68 kg, RT 18.63±0.94 min) who completed more than 17 minutes on the treadmill, while group 2 consisted of those (n=9, age 25.11±6.07 years, height 182.11±10.03 cm, weight 79.72±7.54 kg, RT 15.61±0.64) who completed less than 17 minutes. The cut-off time was the average run time of the players participating in the same football league during the same season, which was demonstrated in a previously published study (Parpa & Michaelides, 2021). Goalkeepers were excluded from the study as they usually work in different intensity zones than the rest of the players (Andrasic, Cvetkovic, Jaksic, & Orlic, 2013). Players were advised to abstain from any activity the day before testing, and measurements were obtained between 8:00 am and 1:00 pm. Each player was briefed on the procedures and signed an informed consent before data collection. Ethical guidelines were followed according to the Helsinki Declaration's ethical standards, and the study was approved by the University's ethics committee board (reference number STEMH 541, 2021).

Procedures

Cardiopulmonary exercise testing

The players completed an incremental maximal cardiopulmonary exercise testing (CPET) until they reached exhaustion on a treadmill (h/p/Cosmos Quasar med, H-P-Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany). A breath-by-breath analysis was performed on the Cosmed Quark CPET (Rome, Italy) system. Laboratory conditions were kept constant, with the temperature at 22±1ºC and relative humidity at 50%. The players were tested utilizing the modified Heck incremental maximal protocol, which was previously used to test soccer players (Parpa & Michaelides, 2022). The test came to an end when the participant reached volitional fatigue or when there was no variation among the VO2 levels while the workload increased. The VO2max was detected after having the results filtered to identify the highest value for an average of 10 seconds.

Determination of Ventilatory Threshold and Respiratory Compensation Point

The ventilatory threshold (VT1) and respiratory compensation point (RC) or VT2 were determined using different criteria. The VT1 was determined through the V-Slope method, the point at which the increase in the rate of elimination of carbon dioxide (VV̇ CO2) is greater than the increase in V̇O2. The VT1 point was verified at the nadir of the VE/VV̇ O2 curve. The RC or VT2 point was determined at the nadir of the VE/V̇ CO2 curve (Beaver, Wasserman, & Whipp, 1986; Takano, 2020). Blood sampling

The Nova blood lactate plus analyzer, which provides a valid and reliable measurement of blood lactate concentration (Hart, Drevets, Alford, Salacinski, & Hunt, 2013) (Nova Biomedical, Waltham, MA 02454), was used following the manufacturer's instructions to measure blood lactate during an incremental exercise testing. Lactate plus single-use test strip was touched to a drop of blood taken via finger prick (0.7 microliters) to initiate the test. The blood lactate values were available on-screen in 13 seconds. Measurements of blood samples were obtained every 3 minutes after completing each stage of the test, with a total of 141 measurements completed. If a stage was not completed, the final blood sample was obtained upon the completion of the test. The lactate measurements were used to identify lactate thresholds through VI, Dmax, modified Dmax, Log-log, and lactate at 4 mmol/l methods, utilizing the Lactate-E version 2.0 software (Galway, Ireland), which was validated in previous studies (Newell et al., 2007).

Statistical Analyses

SPSS 26.0 for Windows (SPSS Inc., Chicago) was used to analyze the results. First, normality and homogeneity of variances were examined and verified using the Shapiro-Wilk and the Brown and Forsythe tests, respectively. In addition, the mean and SD were calculated for all parameters. An independent t-test was utilized to compare the two groups with respect to anthropometric characteristics, run times, and heart rates. Finally, a split-plot ANOVA (Mixed design two-way repeated-measures ANOVA) was utilized to assess between and within-group differences. The between subjects' factor had two levels (group 1 and 2 based on run times), and the within-subjects factor had six levels (VT2, V1, Dmax, modified Dmax, Log-Log, and FBLA at 4mmol/l). For all statistical analyses, significance was accepted at $p<0.05$.

Results

The anthropometric characteristics and RT of the two groups of soccer players are presented in Table 1. Heart rates at different running speeds and heart rates based on the lactate threshold methods are presented in Table 2. No significant differences between the groups were identified regarding the anthropometric characteristics and heart rates (Tables 1 and 2). However, the two groups were significantly different with regard to performance based on RT [($t(23)=8.56$, $p<0.00$, Cohen's $d=3.76$)], and that was the reason they were divided into the two groups. In addition, the speeds for the ventilatory and lactate threshold methods of the two groups are presented in Table 3. Results indicated significant differences between the two groups for the speeds calculated with the VT2 and LT methods except for the Log-Log method (Table 3). Furthermore, multivariate tests indicated no significant differences in the speeds calculated with VT2 and LT methods for groups 1 and 2. A borderline significant difference in the speed calculated for group 1 was indicated between VT2 and Log-Log (15.00±1.46 km/h vs. 13.53±1.59 km/h, $p=0.062$, partial $\eta^2= 0.55$) and VT2 and FBLA at 4mmol/l method (15.00±1.46 km/h vs. 13.66±1.07, $p=0.054$, partial $\eta^2= 0.55$) (Table 3). Lastly, for group 2, no significant differences were identified between the VT2 and LT methods, with the only difference being identified between V1 and Dmax methods ($p=0.043$, partial $\eta^2= 0.87$) (Table 3).

Table 1. Anthropometric characteristics and run time (RT)

	Group 1 (n=16)	Group 2 (n=9)
	Mean ± SD	Mean ± SD
Age (yrs.)	24.38±7.33	25.11±6.07
Height (cm)	180.33±7.03	182.11±10.03
Weight (kg)	75.53±7.68	79.72±7.54
RT (min)	18.63±0.94	15.61±0.64**

*Note: **p<0.01 denotes a significant difference between the groups.

Table 2. Heart rate at different running speeds and heart rate based on the different lactate threshold methods.

	Group 1 (n=16)	Group 2 (n=9)
	Mean ± SD	Mean ± SD
Heart rate at 12km/h	171.81±11.86	171.33±11.44
Heart rate at 14km/h	181.81±10.09	180.89±10.23
Heart rate at 16km/h	190.44±9.70	188.33±8.41
Heart rate at 18km/h	195.63±10.49	
HR at V1	180.81±12.25	175.21±8.92
HR at Log-Log	175.96±16.53	174.83±14.99
HR at Dmax	179.91±12.02	172.87±9.01
HR at Modified Dmax	179.42±12.02	173.20±7.73
HR at FBLA	177.14±11.92	169.69±8.29

*Note: HR at V1: Heart rate based on visual inspection method, HR at Log-Log: Heart rate based on logarithmic method, HR at Dmax: Heart rate based on Maximum distance method, HR at FBLA: Heart rate based on Fixed blood lactate accumulation.

Table 3. Differences in speeds between the two groups and the different methods.

	Group 1 (n=16)				Group 2 (n=9)			
	Mean ± SD	**95% CI for mean**	**p**	**partial η2**	**Mean ± SD**	**95% CI for mean**	**p**	**partial η2**
VT2 speed (km/h)	15.00±1.46 †§	14.22-15.78			13.33±1.41*	12.25-14.42		
V1 speed (km/h)	14.35±1.38	13.62-15.08			13.27±0.77* ‡	12.67-13.86		
Dmax speed (km/h)	14.24±1.03	13.69-14.79			12.90±0.64** ‡	12.41-13.40	0.043	0.87
Modified Dmax speed (km/h)	14.14±1.18	13.51-14.76			12.92±0.74*	12.35-13.50		
Log-Log LT speed (km/h)	13.53±1.59 †	12.68-14.38	0.062	0.55	13.27±1.73	11.94-14.60		
FBLA(4mmol.l) speed (km/h)	13.66±1.07 §	13.09-14.24	0.054	0.55	12.38±1.34*	11.35-13.41		

*Note: VT2: ventilatory threshold 2, V1: visual inspection method, Log-Log: logarithmic method, Dmax: Maximum distance method, FBLA: Fixed blood lactate accumulation, *p<0.05, **p<0.001 denotes a significant difference between the two groups, † denotes a borderline significant difference between VT2 and Log-Log LT for group 1, § denotes a borderline significant difference between VT2 and FBLA for group 1 and ‡ denotes a significant difference between V1 and DMax for group 2.

Discussion

Despite a long research history, the lactate threshold continues to be a widely controversial field. Specific practical difficulties and controversies still exist in LT estimation due to the terminology used and the multiple proposed estimation methods. Notwithstanding the controversies and influence of multiple determinants, estimation of LT in sports has been considered one of the essential parameters in the prescription of training intensity, load monitoring (Sparks Coetzee, & Gabbett, 2016) as well as prediction of performance (Edwards, Clark, & Macfadyen, 2003; Forsyth, Burt, Ridley, & Mann, 2017). Thus, this study aimed to compare the ventilatory anaerobic threshold (VT2) that is used as an indirect marker of LT to the lactate thresholds that derive from the invasive methodology.

This study indicated that the threshold speeds based on the ventilatory anaerobic threshold (VT2) were 15.00±1.46 km/h and 13.33±1.41 km/h for groups 1 and 2, respectively (Table 3). The speeds as determined by the V1, Dmax, modified Dmax, Log-log, and FBLA methods ranged between 13.66 and 14.35 km/h for group 1, while for group 2, they ranged between 12.38 and 13.27 km/h. Similarly, a study of professional German soccer players indicated that at a fixed lactate of 4 mmol/l, the running speed was 15km/h (Altmann, Kuberczyk, Ringhof, Neumann, & Woll, 2018), while in general, a running speed of 14.4km/h at the 4mmol/l is used by sports coaches as the cut-off point (Foehrenbach, Buschmann, Liesen, Hollmann, & Mader, 1986). Concurrently, lower running speeds were indicated in another study on soccer players, where the running speed at the level of the 4 millimolar lactate threshold for first league players was 12.6km/h, while second league players reached the highest running speed at 11.8km/h (Andrzejewski, Chmura, Dybek, & Pluta, 2012). The speeds demonstrated in our study with the FBLA (Lactate=4mmol/l) method were 13.66 km/h and 12.38 km/h for groups 1 and 2, respectively. Furthermore, the higher lactate production at lower running speeds for the second league players demonstrated in the aforementioned study was similar to the results of our study, where players with lower performance demonstrated increased lactate levels at lower running velocities. It should be noted that the FBLA is calculated using inverse prediction and is a marker that represents a ceiling value for lactate (Newell et al., 2007). The main criticism of the FBLA marker is the considerable variability at higher workloads (Newell et al., 2007).

Of note, our study demonstrated no significant differences in the speeds calculated with VT2 and LT methods for groups 1 and 2, suggesting that the VT2 may be used as an alternative to the LT methods for the identification of exercise intensities at which soccer players should train. Another study in soccer players that only examined the agreement between the LT methods but not the association between the VT2 and LT methods indicated poor agreement between VI, Dmax, modified Dmax, and log-log methods for LT measurement in professional soccer players (Cerda-Kohler et al., 2016). Similarly, our results indicated a significant difference between V1 and Dmax methods only for group 2. Furthermore, in agreement with the results of the aforementioned study was the finding that the speed at LT was the lowest with the Log-Log method for group 1, indicating a borderline difference with the VT2 method. It should be noted that the Log-Log method is criticized for taking logarithms of both the lactate and workload, and it assumes that the increase in lactate post LT is exponential. This is difficult to justify as using an exponential function in the model suggests that the rate of change in lactate depends on the amount of lactate (Newell et al., 2007). Despite the criticism for the Log-Log method, our results indicated that even though the speeds at VT2 are slightly higher than those identified with the lactate methods, they are not significantly different. Therefore, the ventilatory threshold speeds can be used as an alternative to the speeds indicated with the LT methods and can be used interchangeably in professional soccer players. Furthermore, these results are comparable to the research on cyclists that demonstrated that lactate threshold tests could be a valid and reliable alternative to ventilatory thresholds (Pallarés et al., 2016).

Last but not least, in a study by Ziogas and Colleagues, the Dmax method was considered the most valid measure of velocity at LT (Ziogas et al., 2011). In their study, the velocities indicated by the Dmax method were 13.2, 12.6, and 12.3 km/h for divisions A, B, and C, respectively (Ziogas et al., 2011). Our study's speeds at LT with the Dmax method were 14.24 km/h for group 1 and 12.90 km/h for group 2, which are similar to the findings of the previously mentioned study. Notably, the Dmax method is dependent on both the initial and final lactate reading, and therefore the initial and final workloads at which the data are collected directly influence this marker (Newell et al., 2007) and thus, this may partially explain the differences between players of different divisions as well as players with significant differences in performance.

In conclusion, the intensities identified with the VT2 are not significantly different from those indicated with the LT measurements in professional soccer players. These findings suggest that VT2 can be used as an alternative to the LT measurements and therefore being able to identify a threshold point without utilizing an invasive procedure enhances the potential application of VT2 or respiratory compensation point. Our results may aid coaches and trainers in the prescription of exercise intensities, especially in the pre-season period, to optimize performance in professional soccer players and verify the effectiveness of their training routines. Furthermore, these results may be combined with video tracking and GPS data to determine fatigue and maximize performance in elite soccer players. Concurrently, VT2 may be used as an alternative to the invasive LT measurements due to its lower cost.

Limitations

A major limitation of this study is the small sample size. Nevertheless, this may serve as a pilot study demonstrating the potential use of VT2 as an alternative to the LT invasive measurements. Therefore, future studies with a larger sample size are needed to confirm the results of this study. Also, further research is encouraged to clarify the validity of these results in soccer players of different age groups, divisions, playing positions, and female soccer players.

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Conflict of Interest
The author declares that there is no conflict of interest.

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