Velocity at Lactate Threshold and Running Economy Must Also be Considered Along With Maximal Oxygen Uptake When Testing Elite Soccer Players During Preseason

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VELOCITY AT LACTATE THRESHOLD AND RUNNING ECONOMY MUST ALSO BE CONSIDERED ALONG WITH MAXIMAL OXYGEN UPTAKE WHEN TESTING ELITE SOCCER PLAYERS DURING PRESEASON

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ABSTRACT

Maximal oxygen uptake ($\dot{V}O_2max$) has been traditionally used to explain physiologic differences among soccer teams of different ranking. However, other endurance markers may have greater discriminatory ability. The purpose of this study was to examine whether velocity at lactate threshold and running economy can be used to better discriminate endurance characteristics of soccer teams of different levels along with $\dot{V}O_2max$ during preseason testing.

One hundred twenty-nine professional Greek soccer players participating in the top 3 divisions underwent an incremental treadmill test to exhaustion using expired gas analysis and simultaneous blood lactate measurements. Velocity at lactate threshold was determined using the Dmax method, and running economy was measured at 12 km·h^{-1}. Analyses of variation were used to compare for differences between divisions. Velocity at lactate threshold was the only variable that was statistically different between any 2 divisions. In every comparison, the higher division had the higher velocity at lactate threshold. The $\dot{V}O_2max$ was statistically different between divisions with similar $\dot{V}O_2max$, with better running economy for the higher division in each comparison. These results indicate that velocity at lactate threshold can be used to better discriminate endurance characteristics of soccer teams of different level along with $\dot{V}O_2max$ during preseason testing. Running economy may reveal differences between teams with similar $\dot{V}O_2max$.

INTRODUCTION

High-level soccer performance requires technical, tactical, and mental skills as well as physical capacities. During a competitive match, elite players cover 10 to 12 km (3,28) at approximately 8–90% of their maximum heart rate (HRmax) (3,19), which corresponds to approximately 75–80% of maximal oxygen uptake ($\dot{V}O_2max$) (2). Aerobic energy contributes an average of 90% of the total energy cost in a soccer match (3,4). During the last 10 years, greater attention had been placed on physical capacities because it was found that the most successful teams had greater values compared with less successful teams (26,36). The $\dot{V}O_2max$ is considered the most important component of aerobic endurance performance, and most soccer studies have extensively examined differences in $\dot{V}O_2max$ among teams of different levels. It has been reported that in elite soccer, $\dot{V}O_2max$ values greater than 21 lactate threshold. The $\dot{V}O_2max$ was statistically different only 60 ml·min·kg^{-1} are required during in-season and that in some cases team ranking may be explained by differences in $\dot{V}O_2max$ (1,15,36).

The relationship between $\dot{V}O_2max$ and ranking, however, has been questioned in other endurance sports. Studies on elite endurance cyclists as well as middle- (3–10 km) and long-distance (10 km+) runners have reported that velocity at lactate threshold (vLT) rather than $\dot{V}O_2max$ is more strongly correlated to endurance performance, and vLT may better differentiate among elite athletes (7,16,18). Soccer has a similarity in the distance covered with the above groups but differs in the type of actions and intensity because more than 150 different brief intense activities are performed in a game (28). Although soccer involves an intermittent type of activity between moderate- and high-intensity actions during a game, in both endurance running and soccer, oxygen delivery is high because HR is rarely below 65% of maximum. Because vLT is better related to success in elite endurance runners than $\dot{V}O_2max$ (5,12,30), it appears to be an important parameter to consider in soccer. Furthermore, vLT responds to soccer training with the threshold occurring at higher running velocities (19,24,27), even in the absence of change in $\dot{V}O_2max$ (14). Because vLT is strongly related to endurance performance and it is affected by soccer training, it was hypothesized that it may be an important physiologic facot to consider along with $\dot{V}O_2max$ and may differ between different divisions.

In the few soccer studies that have examined vLT, a fixed blood lactate value (4 mmol·L^{-1}) was used based on a linear extrapolation, or the same team was been tested during the season (14,26,27). To our knowledge, there are no vLT data for teams of different divisions. Also, the use of a fixed blood lactate concentration as indicator of LT has been questioned because lactate accumulation follows a curvilinear response. It is well established that steady-state blood lactate concentrations may vary widely among individuals, and, therefore, a fixed blood lactate concentration may not represent a ''threshold'' for all subjects (12,34). Therefore, a mathematically derived threshold, rather than a ''fixed'' threshold, may more accurately identify differences in endurance characteristics of soccer players. Indeed, previous studies indicated that, in endurance runners, lactate threshold velocity, determined by the Dmax method, is more strongly correlated with performance as compared with the ''fixed'' 4 mmol·L threshold (30). Thus, in the present study, the Dmax method was used to determine vLT.

In some endurance studies, authors have suggested that running economy (REcon) may also affect endurance performance and discriminate among elite runners, even when $\dot{V}O_2max$ remains unaltered (11,20,31). Most of the studies in REcon are based on data from distance runners or cyclists, in whom the relationship between time and REcon is well documented. Conley and Krahenbul (11) reported high correlation between REcon and 10-km time in endurance runners. In addition, it has been reported that a 5% improvement in REcon may increase the distance covered in a soccer match by approximately 1,000 m, even in the absence of an improved $\dot{V}O_2max$ (20). Thus, REcon may also be an important parameter to consider when testing the physical capacities of soccer players during preseason and may differ especially between teams or divisions with similar $\dot{V}O_2max$ values.

Therefore, the aim of the study was to examine whether vLT and REcon also differ among teams of different divisions and whether this difference can be used to better discriminate endurance characteristics of soccer teams of different divisions along with $\dot{V}O_2max$ during preseason testing. We hypothesized that a) vLT would differ among teams of higher and lower divisions along with $\dot{V}O_2max$, but vLT would be a more sensitive indicator for discriminating among higher and lower divisions compared with $\dot{V}O_2max$ and b) Recon would discriminate between divisions with similar $\dot{V}O_2max$ values.

METHODS

Experimental Approach to the Problem

In the present study, we recruited male professional soccer players. To test our hypotheses, $\dot{V}O_2max$, vLT, and REcon were all determined using a single incremental treadmill test with simultaneous respiratory gas exchange analysis and blood lactate measurements. To obtain reliable measures for the respiratory variables and blood lactate values, an incremental test design (e.g., stage duration) was selected according to proposed recommendations (6). Experimental testing took place in a university laboratory at an ambient temperature of 20°C to 22°C. All teams were tested within 2 consecutive days, from 9 am to 3 pm depending on the number of players from each team. The same testing schedule was used for all participating teams. Therefore, circadian rhythm had probably the same impact on every team. All testing was conducted during the first week of the preseason training period. Before testing and during the last 3 weeks, all participants performed 20 to 30 minutes of moderate-intensity running 1 or 2 times per week. Because of different starting dates in each division, testing was not performed during the same week, but all players were tested in the same month (July).

Subjects

One hundred twenty-nine professional soccer players agreed to participate in the study. Fifty-three of them were from 3 teams of the top Greek National Division (Division A), 46 players were from 3 teams of the Second Division (Division B), and 30 players were from 2 teams of the Third National Division (Division C). At the end of the season, all participating teams finished at the top half of their division. All players were competing at a professional level for an average of 6 years. They had also participated in similar type of testing in the past and were familiar with the procedures, discomforts, and possible risks of the present study. Before testing, subjects were informed again about the experimental procedures, filled out a medical questionnaire, and signed a consent form according to the Declaration of Helsinki. Ethical approval was granted from the institutional review board of human subjects. The characteristics of the subjects are presented in Table 1.

TABLE 1. Group means (*SD*) of physical characteristics of players who participated in study.*

	Age (yr)	Height (cm)	Body mass (kg)	Body fat (%)
Division A ($n = 53$)	26.2 (4.9)	181 (5.8)	78.0 (6.8)	10.6 (2.9)
Division B ($n = 46$)	25.9 (5.2)	181 (5.2)	76.4 (5.9)	11.1 (2.8)
Division C ($n = 30$)	25.6 (4.5)	180 (5.4)	77.1 (6.7)	10.8 (2.7)

**SD* is 1 standard deviation.

Procedures

Subjects reported to the laboratory at a fully hydrated state, having abstained from caffeine for 4 hours and vigorous training for 48 hours. They were also given instructions to follow a specific diet (55–60% carbohydrates, 20% protein, and 20–25% fat) the day before testing and eat a high carbohydrate meal (60% carbohydrates, 300–400 kcal) 4 hours before testing. Height and weight were measured using calibrated statiometer and scale (Seca, Hamburg, Germany). Percent fat was assessed using a skinfold calliper (Lange, Beta Technology, Santa Cruz, CA, USA) and was calculated based on the 7-site Jackson and Pollock formula (25).

During warm-up, the subjects performed 3 minutes of walking at their self-selected pace and 5 minutes of jogging on a treadmill (Technogym Runrace 1200, Gambettola, Italy) at a speed of 8 $km \cdot h^{-1}$ during which HR and lactate were measured. Then, subjects performed an incremental exercise test to volitional exhaustion with expired gas and HR analysis using a computerized system (CPX Ultima, Medical Graphics, St. Maul, MN, USA) to determine $\dot{V}O_2max$, vLT, and REcon. This system uses an infrared sensor and a zirconium oxide electrode for measuring fractional concentration of CO_2 and O_2. A pneumotachograph (prevent, Medical Graphics, St Maul, MN, USA) was used to measure expired gas volume. Immediately before each test, known-composition gases and a 3-L Rudolph syringe were used for calibration of the gas analyzers and the pneumotachograph, according to the manufacturer's instructions. The initial speed of the incremental test was set at 10 $km \cdot h^{-1}$ and was increased by 2 $km \cdot h^{-1}$ min^{-1} every 3 minutes until volitional exhaustion (6). At the end of each 3-minute stage, the subjects grasped the side bars of the treadmill and moved their feet on the sides of the treadmill belt. Capillary blood samples were then collected and analyzed for lactate using an automated analyzer (Accutrend, Roche Diagnostics, Mannheim, Germany). Subjects recommenced running within 20 seconds. Criteria for $\dot{V}O_2max$ were a) plateau in $\dot{V}O_2$ (an increase less than 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ despite an increase in running speed), b) respiratory exchange ratio (RER) greater than 1.10, (c) HR +/- 5% of age predicted HRmax, and (d) maximal blood lactate after exercise greater than 8 $mmol \cdot L^{-1}$. In all cases, at least 3 of 4 criteria were met. REcon was calculated using the average $\dot{V}O_2$ of the last 30 seconds at 12 $km \cdot h^{-1}$. This speed was chosen for Recon because it corresponded to below 85% of $\dot{V}O_2max$ because, for reliable measures of Recon, speeds that elicit 85% or less of $\dot{V}O_2max$ are required (33). Blood lactate values were plotted against speed, and the data were fitted using a third degree polynomial curvilinear regression (9). The Dmax method was used for LT determination (8,9,30).

Statistical Analyses

One-way analysis of variation with Tukey-Kramer adjustment for multiple comparisons was used to determine significant differences between group means for the following dependent variables: $\dot{V}O_2max$ and vLT based on the Dmax method, lactate concentration at LT, HR at LT, HRmax, and REcon. The level of significance was set at 0.05. Sample size estimation revealed that a total of 103 athletes would be sufficient to detect ''moderate effects'' with a statistical power of 0.90 at an alpha level of 0.05. Thus, we are confident that our study had the necessary power to detect the existence (or absence) of significant differences between divisions for any of the tested dependent variables. Effect sizes were also calculated to address the magnitude of the responses (10). In addition, we recruited 10 amateur, well-trained soccer players that performed the incremental treadmill test used in the present study, within a 2-week time interval to determine the intrasubject reliability. The typical error of measurement (TE as percent coefficient of variation [%CV]) and the correlation coefficient (*r*) were used to quantify reliability (21,22). The TE is a contemporary measurement of reliability, and this value represents the variation in a subject's score from measurement to measurement (21).

Table 2. Group means (*SD*) of all dependent variables tested for 3 soccer divisions.

	Division A ($n = 53$)	Division B ($n = 46$)	Division C ($n = 30$)
$\dot{V}O_2$ ($ml \cdot min^{-1}$)	4,577.5 (401.2)‡	4,300.7 (348.1)	4,32.0 (370.5)
$\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	58.8 (3.3)‡	56.4 (3.7)	57.6 (3.2)
$\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-0.75}$)	174.4 (9.3)‡	166.5 (10.1)	170.5 (8.7)
LT ($mmol \cdot L^{-1}$)	3.9 (1.2)	3.8 (1.2)	3.9 (1.8)
vLT ($km \cdot h^{-1}$)	13.2 (0.7)†‡	12.6 (0.7)†	12.3 (0.8)
HR LT (bpm)	170 (10)	167 (11)	168 (11)
REcon ($ml \cdot min \cdot kg^{-1}$)	44.6 (2.9)†	44.4 (2.8)†	46.4 (3.9)
HRmax	191 (9)	191 (9)	191 (8)

SD is 1 standard deviation.
*$\dot{V}O_2$ = oxygen uptake; LT = lactate threshold; vLT = velocity at lactate threshold; HR = heart rate; REcon = running economy; HRmax = maximum heart rate.
†Significantly different from division C ($p < 0.05$).
‡Significantly different from division B ($p < 0.05$).

Table 3. Mean (*SD*) values for test-retest and reliability of maximal oxygen uptake, velocity at lactate threshold, and running economy.*

	Test 1	Test 2	Typical error (as %CV)	Correlation coefficient (*r*)
$\dot{V}O_2max$ ($ml \cdot min^{-1}$)	3,971.1 (325.8)	3,906.2 (312.2)	2.4	0.91
$\dot{V}O_2max$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	57.1 (4.9)	56.5 (5.4)	2.5	0.92
$\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-0.75}$)	164.5 (10.0)	162.5 (11.0)	2.5	0.85
vLT ($km \cdot h^{-1}$)	13.4 (1.4)	13.2 (1.2)	2.0	0.95
REcon ($ml \cdot min \cdot kg^{-1}$)	44.3 (1.9)	43.4 (2.0)	2.0	0.8

SD is 1 standard deviation ($n = 10$).
*CV = coefficient of variation; $\dot{V}O_2max$ = maximal oxygen uptake; $\dot{V}O_2$ = oxygen uptake; vLT = velocity at lactate threshold; REcon = running economy.

RESULTS

No significant differences were found between divisions for age, height, body weight, and percent body fat ($p > 0.05$) (Table 1). All other tested variables are presented in Table 2.

Velocity at LT and $\dot{V}O_2max$

The vLT was significantly different between divisions A versus B ($p < 0.05$, effect size = 0.9), A versus C ($p < 0.05$, effect size = 1.2), and B versus C ($p < 0.05$, effect size = 0.4), with consistently higher mean velocity for the higher ranked category in every pair, despite similar blood lactate concentration among groups. The $\dot{V}O_2max$ was significantly higher only for division A versus B ($p < 0.05$, effect size = 0.7), both as an absolute value and in relation to body weight. This finding did not change even when the dimensional scaling approach was used ($p < 0.05$, effect size = 0.8) (7). Heart rate at LT and HRmax did not differ between divisions.

Running Economy

In divisions in which $\dot{V}O_2max$ was statistically different, Recon did not differ (division A vs. B). In contrast, in divisions with similar $\dot{V}O_2max$ (division A vs. C and B vs. C), Recon was significantly different ($p < 0.05$, effect size = -0.6 and -0.5, respectively). In these comparisons, the higher ranked divisions always had better REcon. The REcon corresponded to 75.9—80.5% of $\dot{V}O_2max$ for all divisions.

Reliability

All 3 endurance markers showed high reproducibility. Table 3 presents mean (*SD*) values for the test-retest, TE expressed as %CV, and correlation coefficients for $\dot{V}O_2max$, vLT, and REcon.

DISCUSSION

Previous soccer studies have focused on the significance of $\dot{V}O_2max$ as the variable that can distinguish endurance characteristics between higher and lower ranked soccer teams (1,35). However, this is not always the case (15). In addition, previous studies in other endurance sports have indicated that $\dot{V}O_2max$ is not a good predictor of endurance performance (5). They have also indicated that other variables such as vLT and REcon may better explain more of the variance (16,20,31). Therefore, the aim of the present study was to examine whether vLT and REcon can also be used to better discriminate endurance characteristics soccer teams of different divisions, along with $\dot{V}O_2max$, during preseason testion. We hypothesized that a) vLT would differ among teams of higher and lower division along with $\dot{V}O_2max$ but vLT would be a more sensitive indicator for discriminating among higher and lower divisions compared with $\dot{V}O_2max$, and b) REcon would discriminate between divisions with similar $\dot{V}O_2max$ values.

The major finding of the present study was that, during early preseason, vLT is the only physiologic variable that differs significantly among the 3 divisions. Specifically, higher divisions always had significantly higher vLT in every comparison. In contrast, absolute or relative $\dot{V}O_2max$ differed only when divisions A versus B were compared. This finding supported our first hypothesis. Both vLT and $\dot{V}O_2max$ are considered important parameters of endurance performance, but most authors agree that vLT may be a more sensitive indicator of aerobic endurance as compared with $\dot{V}O_2max$ (12,16,18). This is further supported by Basset and Howley (5), who showed that vLT integrates $\dot{V}O_2max$, %$\dot{V}O_2max$, and REcon and therefore can explain differences in aerobic endurance better than $\dot{V}O_2max$ alone. The $\dot{V}O_2max$ is mainly affected by central factors, whereas vLT is affected by both central and peripheral factors (12,23). This may explain the greater discriminatory power of vLT. The higher vLT observed in the higher soccer divisions has important implications for preseason testing and training. Preseason testing should incorporate vLT testing to examine any potential differences in vLT. In addition, preseason training programs should give emphasis on improving vLT, especially for lower division teams as compared with top division teams because vLT reflects the training status of professional soccer players (14).

To our knowledge, there are no other soccer studies that have examined vLT between different divisions of soccer during preseason. This is in contrast with $\dot{V}O_2max$, which has been studied extensively. Some studies have measured vLT but within the same group and have used a fixed blood lactate value to test LT (14,26,27). However, individual lactate threshold concentration may vary widely (12,34), and, therefore, a fixed blood lactate concentration does not represent individual LT. In the present study, the Dmax method was used because is considered to be the most sensitive and valid measure of vLT as compared with other methods for detecting lactate threshold (8,30,37). Previous studies have examined different indices of lactate threshold in cyclists (8) or 10-km runners (30) including the Dmax method and fixed blood lactate concentration (4 mmol·L^{-1}). These studies concluded that the Dmax was the most sensitive and valid method of vLT and better correlated with endurance performance.

Another observation in the present study was that $\dot{V}O_2max$ was significantly different only for the comparison between divisions A versus B. This is in agreement with previous reports (15) indicating that $\dot{V}O_2max$ may not always differ between higher and lower ranked teams. The $\dot{V}O_2max$ is mainly linked to central adaptations, presumably maximal cardiac output, whereas vLT incorporates both central and peripheral adaptations (12). This may explain why vLT revealed significant differences even when $\dot{V}O_2max$ failed to do so. This finding emphasizes the necessity to assess not only $\dot{V}O_2max$ but also vLT during preseason testing. Thus, it has important implications for soccer training. If both vLT and $\dot{V}O_2max$ are low, training methods that focus on both cardiac output and peripheral adaptations must be incorporated. On the other hand, when only vLT is lower but $\dot{V}O_2max$ is normal or high, training programs should focus mostly on improving vLT.

With respect to our second hypothesis, REcon was significantly different only between divisions with similar $\dot{V}O_2max$ values (A vs. C and B vs. C), which is in agreement with our hypothesis. This is also supported by other investigators who have shown that REcon may explain part of difference in performance when $\dot{V}O_2max$ is similar between groups (11). In the present study, when divisions with similar $\dot{V}O_2max$ were compared, REcon was 4-6% better for the higher division (A vs. C and B vs. C). DiPrampero and coworkers (13) showed that a 5% improvement in REcon will increase the distance running performance by 3.8%. This finding also has important implications for preseason soccer training because certain types of training have a greater impact on REcon (e.g., long, continuous runs or long intervals vs. short intervals) (17,24). Therefore, REcon is an important factor to consider when teams or groups with similar $\dot{V}O_2max$ are compared. It may also explain some of the observed differences in physical performance.

Because preseason training is considered the most important training period for developing the physical capacities of soccer players, tests are routinely conducted during early preseason, and follow-up tests are performed in-season to track any possible changes in aerobic capacity (14,24). An assumption in the present study is that none of the athletes had a significant volume of individual training during off-season. Although their off-season activity was not recorded, in the pretest questionnaire, they had reported that they did not participate in a regular training program more than 2 days per week during the last 3 weeks before testing. In addition, their mean $\dot{V}O_2max$ (56.4 ± 3.7 to 58.8 ± 3.3) is well within the acceptable values at the very beginning of preseason training and supports their statement. Therefore, the similar narrow range of mean $\dot{V}O_2max$ observed in this study among divisions is attributed to the lack of a significant off-season training effect for all subjects. Furthermore, the length of the off-season was almost the same for all teams (5–6 wk) and lasted from late May until early July, depending on the schedule of each team. This summer break is probably sufficient to cause a decrease in both $\dot{V}O_2max$ and vLT (29).

In conclusion, although $\dot{V}O_2max$ is an important parameter to evaluate, when testing elite soccer players, vLT and REcon must also be incorporated in the routine preseason testing of soccer players along with $\dot{V}O_2max$. Teams from different divisions differ in endurance markers, such as vLT or Recon, even when $\dot{V}O_2max$ is similar. These differences must be examined because they can provide important information that will affect preseason training planning.

PRACTICAL APPLICATIONS

The $\dot{V}O_2max$ values combined with both vLT and REcon determination may provide a more precise determination of endurance characteristics of a team than $\dot{V}O_2max$ alone during preseason testing. It appears that the beginning of the preseason period, superior peripheral rather than central adaptations distinguish higher division soccer players from their lower division counterparts. These differences can assist coaches and trainers to plan the preseason training program according to their goal because different training intensities and volumes are required to improve vLT, $\dot{V}O_2max$, and REcon. For example, in teams or soccer players with lower $\dot{V}O_2max$ values, high-intensity training (e.g., 90-95% of HRmax) will increase cardiac output. This may have a more positive effect on $\dot{V}O_2max$ as compared with lower-intensity and higher training volume for REcon improvement. Furthermore, mathematically derived lactate thresholds (e.g., Dmax) may be more precise than fixed blood lactate concentration thresholds (e.g., 4 mM) to determine vLT.

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