©Journal of Sports Science and Medicine (2003) **2,** 23-29
http://www.jssm.org

Research article

LACTATE AND VENTILATORY THRESHOLDS REFLECT THE TRAINING STATUS OF PROFESSIONAL SOCCER PLAYERS WHERE MAXIMUM AEROBIC POWER IS UNCHANGED

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Received: 21 November 2002 / Accepted: 15 January 2003 / Published (online): 01 March 2003

ABSTRACT
The aim of this study was to investigate maximum aerobic power (VO_2 max) and anaerobic threshold (AT) as determinants of training status among professional soccer players. Twelve professional 1st team British male soccer players (age: 26.2 ± 3.3 years, height: 1.77 ± 0.05 m, body mass: 79.3 ± 9.4 kg) agreed to participate in the study and provided informed consent. All subjects completed a combined test of anaerobic threshold (AT) and maximum aerobic power on two occasions: Test 1) following 5 weeks of low level activity at the end of the off-season and Test 2) immediately following conclusion of the competitive season. AT was assessed as both lactate threshold (LT) and ventilatory threshold (V_T). There was no change in VO_2 max between Test 1 and Test 2 (63.3 ± 5.8 $ml \cdot kg^{-1} \cdot min^{-1}$ vs. 62.1 ± 4.9 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively), however, the duration of exercise tolerance (ET) at VO_2 max was significantly extended from Test 1 to Test 2 (204 ± 54 vs. 228 ± 68 s respectively) ($P<0.01$). LT oxygen consumption was significantly improved in Test 2 versus Test 1 ($P<0.01$) V_T was also improved ($P<0.05$). There was no significant difference in VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) corresponding to LT and V_T. The results of this study show that VO_2 max is a less sensitive indicator to changes in training status in professional soccer players than either LT or V_T.

KEY WORDS: VO_2 max, anaerobic threshold, lactate threshold, ventilatory threshold.

INTRODUCTION

Physiological measurements of maximum aerobic power (VO_2 max) and anaerobic threshold (AT) have commonly been used to monitor the fitness and training status of athletes. In soccer, previous studies have demonstrated that players with a higher maximum aerobic power cover greater distance during a soccer game (Bangsbo et al., 1994) and also complete more sprints (Smaros, 1980). The average work intensity during a soccer match has been reported to be ~75 % of VO_2 max, resembling typical values of AT (Reilly 1994, Bangsbo et al. 1994). It is, therefore, likely that despite their non-sport specific design, both VO_2 max and AT are important measurements for soccer players.

The mean VO_2 max of elite soccer players has typically reported to be in the region of 55 to 65 $ml \cdot kg^{-1} \cdot min^{-1}$ (Ekblom, 1986; Reilly and Thomas 1975; Nowacki et al., 1988). However, these values are relatively modest in comparison with elite endurance athletes in other sports such as rowing, cycling or running (Costill et al., 1976; Saltin et al., 1967). To some extent, this may be explained by the high volume of matches completed over the competitive season that reduce the opportunities for aerobic fitness training. It is also likely that elite soccer players are successful because they have good, but not exceptional, all round physical strengths and are thus able to effectively respond to the diverse demands of the game.

Tests of AT can be used to characterise training effects, evaluate physical fitness and provide the relative training intensity in sports where aerobic metabolism is of importance (Allen et al., 1985; Bishop et al., 1998; Brettoni et al., 1989). In endurance sports, it has been suggested that AT might be a better indicator of aerobic endurance than VO_2 max, as AT may change without changes in VO_2 max (Allen et al., 1985; Bishop et al., 1998). In terms of soccer performance, this could mean that a player with a higher AT is able to cover more distance, in comparison with less aerobically trained athletes, during a game at a higher intensity without accumulation of lactate. For the detection of AT, several techniques and criteria have been used on lactate concentration (ADAPT, 1995; Beaver et al., 1985; Ivy et al 1980; Kinderman et al., 1979) and ventilatory parameters (Wasserman, 1978; Beaver et al., 1986a) during exercise.

Measurement of AT using blood lactate concentration has been directed on identifying either the initial rise in lactate above the resting baseline (LT) or the application of a fixed point at 4 $mmol{\cdot}L^{-1}$ (OBLA). OBLA has been widely used to identify changes in training state, however, it's use has been criticised due to variability between subjects (Coyle, 1995) and also because it may be a result of not only muscle anaerobisis, but also a decreased total lactate clearance or increased lactate production in specific muscles (Hermansen, 1971). LT represents the first breakpoint in the lactate profile from the resting level and also appears consistent with the ventilatory threshold (VT) described by the V slope method (Beaver et al., 1986a), therefore, although LT and VT are independent of each other, it is likely that there is a link between ventilatory changes and cellular events. Nevertheless, there is evidence to suggest that any point consistently used from the lactate concentration curve during exercise can be used as a performance index (Tokmakidis et al., 1998).

The aim of this study was to examine whether a difference exists in the laboratory measurements of VO_2 max and AT between off- and on-seasons in elite professional soccer players. This would have important implications for the routine assessment of aerobic or endurance fitness in soccer players.

METHODS

Subjects

Twelve professional 1st team British male soccer players (age: 26.2±3.3years, height: 1.77±0.05m, mass: 79.3±9.4kg) agreed to participate in this study and provided their informed consent in accordance with the Ethics Committee of Reading University.

Training status

Test 1 - Off-season

The aim of the off-season period was to enable the players to recuperate following the rigors of the competitive season while completing sufficient exercise to retain an adequate level of fitness for development in the pre-season phase of training. The off-season period was reduced from the usual 9 weeks to 5 weeks due to promotional play-off matches. Over the 5 week period, all players were requested to complete 2 aerobic runs a week (1 x 80 – 90% HR max for 25 mins and 1 x 60 – 70% HR max for 25 mins), and 1 muscular strength session a week of moderate intensity utilising both upper and lower body exercises of the major muscle groups (4x 12 @ 50% 1RM).

Test 2 - On-Season

Following the off-season, players completed a total of 14 hours of effective training per week in the pre-season phase and all subjects performed all, or part, of 3 competitive games in this period. The emphasis of the pre-season phase was on regaining, and where possible, improving previous fitness levels prior to the new season. Over the competitive season, the average training week consisted of 6, 2 hours practice and games with emphasis on technical and tactical aspects of the game. The opportunities for specific fitness training sessions were minimal over the season. The total number of competitive 1st team games for the season was 53 and the subjects in this study completed a mean of 32 (±6).

Exercise Protocol

All subjects completed a combined test of anaerobic threshold (AT) and aerobic capacity (VO_2 max) on two occasions: Test 1) following 5 weeks of low level activity at the end of the off-season and Test 2) immediately following conclusion of the competitive season. All tests were completed on a computer controlled treadmill (Woodway PPS 55, Germany) and the test comprised a series of incremental steps which increased in speed every 3.5 min to a maximum of 4.03 $m{\cdot}s^{-1}$. The test started with a warm up of 2 min at a walking pace of 0.97 $m{\cdot}s^{-1}$ and was followed by 3 min at 2.78 $m{\cdot}s^{-1}$ prior to the first stage of the test. The test was designed to enable the subjects to reach aerobic steady state within 3 min in each stage with a further 30s included in each stage for the collection of blood samples. During each 30s period, subjects were stationary before recommencing the test for the next 3 min stage. After the final 3 min stage at 4.03 $m{\cdot}s^{-1}$ was completed, the incline of the treadmill was increased by 2% every minute until a plateau in VO_2 could be observed, after which time the subject completed maximal exercise at a constant velocity (Figure 1). Criteria from British Association of Sport and Exercise Sciences (1997) was used to ascertain a maximum aerobic power had been attained and the length of exercise tolerance was calculated from the initial VO_2 peak to the end of the VO_2 plateau when

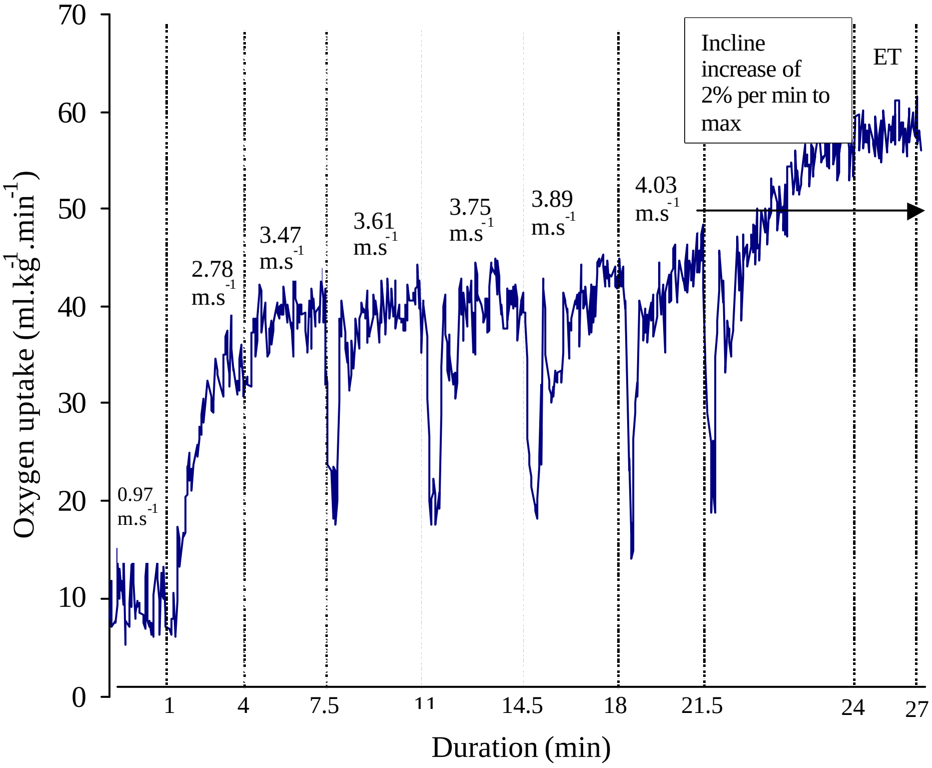

Figure 1. Breath-by-breath oxygen uptake (VO_2) for a single subject in response to the combined test of anaerobic threshold and maximum aerobic power.

the subject was unable to maintain a constant velocity.

Anaerobic threshold was assessed as the oxygen consumption corresponding to both lactate threshold (LT) and ventilatory threshold (V_T). LT was expressed as the VO_2 immediately preceding a 0.4 mM increase in lactate concentration above the baseline value (ADAPT, 1995) and V_T was identified by the V slope method, described by Beaver et al., (1986).

Measurement of gas exchange parameters

VO_2, VCO_2 and VE were measured breath-by-breath using a Cortex 3B Metalyser (Cortex Biophysik Germany).

Blood sampling and anthropometric measurement

Blood was sampled from the fingertip. A small incision was made using a single use disposable lancet (Mirotainer; Becton Dickinson, NJ, USA). The blood samples collected in the 30s periods between each 3 min step increase in work rate stages and were immediately analysed for whole blood lactate concentration using an Analox GM7 Analyser (Analox Instruments, London, U.K).

Body fat was assessed by bioelectrical impedence (Tanita TBF-551 Body composition scales). Ambient temperature was maintained between 16-18 °C and testing was conducted at the same time of day in each testing session. Subjects were allowed 2ml· kg· BM^{-1} of water in the hour preceding testing to standardise hydration levels. Body mass and height were calculated using standard laboratory measurement techniques.

Statistical Analysis

Student paired ‘t’ tests were used to examine the difference between Test 1 and Test 2.

RESULTS

There was no change in VO_2 max between Test 1 and Test 2, although a lower mean was recorded in Test 2 (Table 1). The overall test duration was significantly extended from Test 1 to Test 2 (27.5 ±1.4 min and 28.1 ±1.5 min respectively $p < 0.05$) and the period of exercise tolerance (ET) at VO_2max was also significantly extended in Test 2 when the

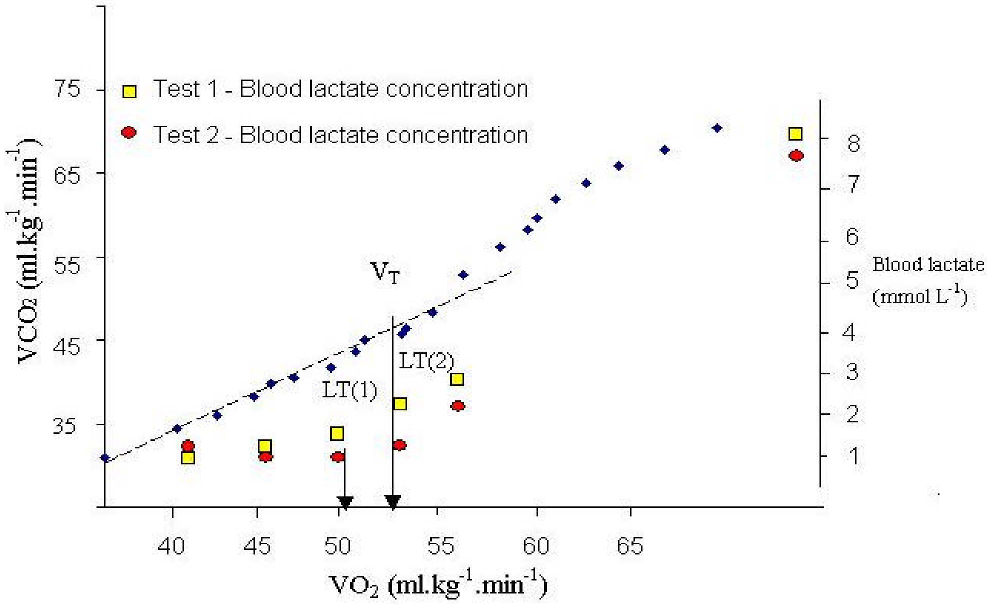

Figure 2. Gas exchange and blood lactate response from a single subject in response to the combined test of anaerobic threshold (AT) and maximum aerobic power (VO_2 max). VT = ventilatory threshold, LT(1)= Lactate threshold (Test 1), LT(2)= Lactate threshold (Test 2).

players were in a highly trained state ($p < 0.01$) (Table 1). The period of ET can be seen for a single subject in Figure 1. Body mass had decreased significantly from the off-season to the end of the season (79.3 kg ±9.36, 77.2 kg ±6.34 respectively) ($p < 0.05$) and percentage body fat had also decreased significantly by Test 2 (12.3% ±3.11 and 11.8% ±2.4) ($p < 0.01$).

Table 1. Maximum oxygen uptake (VO_2max, $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) and the duration of exercise tolerance (ET, second) at VO_2 max following the off-season (Test 1, n=12) and on-season (Test 2, n=12). Data are mean (SD).

	Test 1	Test 2
VO_2max	63.3 (5.77)	62.1 (4.93)
ET	204 (54)	228 (68) **

** denote significant ($p < 0.01$) difference between Test 1 and Test 2.

Anaerobic threshold, defined as LT oxygen consumption was significantly improved by Test 2 ($p < 0.01$) (Figure 2), which was also the case when expressed as V_T ($p < 0.05$) (Table 2). The percentage of LT to VO_2 max increased significantly from Test 1 to Test 2 (81% and 86% respectively $p < 0.01$) and this was also the case for V_T (80% and 85% respectively $p < 0.05$). There was no difference in VO_2 ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$) corresponding to LT or V_T (Figure 2).

Table 2. Oxygen consumption ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$) at lactate (LT) and ventilatory thresholds (V_T) following the off-season (Test 1, n=12) and on-season (Test 2, n=12). Data are mean (SD).

	Test 1	Test 2
LT	51.47 (4.2)	53.49 (3.5) **
V_T	50.73 (4.83)	52.59 (4.13) *

* and ** denote significant ($p < 0.05$ and $p < 0.01$, respectively) differences between Test1 and Test 2.

Resting lactate did not differ between exercise tests (1.1 ±0.8 $mmol{\cdot}L^{-1}$ and 1.2 ±0.6 $mmol{\cdot}L^{-1}$) or in maximum lactate concentrations immediately following testing (Test 1 - 8.12 ±1.5 $mmol{\cdot}L^{-1}$ and Test 2 - 8.4 ±1.1 $mmol{\cdot}L^{-1}$). However, there was a trend for higher maximal lactate concentrations in Test 2 ($p < 0.09$).

DISCUSSION

An interesting finding of this study was that the oxygen consumption at both LT and V_T were significantly elevated in Test 2 when the elite soccer players were in a highly trained state (Table 2). However, there was no difference in VO_2 max between Test 1 and Test 2, suggesting that this measurement is less sensitive to training status in soccer players than either V_T or LT.

Several studies have demonstrated that in the general population, aerobic training often improves the exercise intensity corresponding to anaerobic threshold without a concomitant increase in VO_2 max (Bishop et al., 1998; Fouquet and Poty, 1982) and this study of elite soccer players is consistent with that observation. Nevertheless, VO_2 max is routinely used to describe and monitor changes in aerobic training status in elite soccer players and this study demonstrates that there may be a limitation to the usefulness of this procedure.

One explanation for the unchanged VO_2 max measurements could be drawn from the difference in the duration of exercise tolerance at VO_2 max. This period was significantly extended in Test 2 ($p < 0.01$), suggesting that in a highly trained state, subjects were able to supplement additional exercise performance time through enhanced anaerobic energy systems. Lactate concentration was not significantly elevated in Test 2 possibly due either to an enhanced buffering capability or improved acid-base regulation (Beaver et al., 1986b; Stringer et al., 1992). As no difference was found in maximum lactate at exhaustion, it is unlikely that the increased duration of exercise tolerance can be attributed to motivational factors, and therefore, the VO_2 max of the elite soccer players in this study may have reached a level at which further improvement could be minimal. This is consistent with the observation of a high genetic contribution to VO_2 max performance, thus restricting the potential for improvement (Bouchard et al., 1992; Bouchard et al., 1994), especially in elite athletes with well-developed exercise capacities.

In terms of AT assessment, traditional concepts indicate that the threshold point should correspond to the capacities and limitations of the cardio-pulmonary system as well as the optimal supply of energy using cytosol and mitochondrial enzymatic activities (Coggan et al., 1992; Holloszy and Coyle, 1984; Tokmakidis et al., 1998). Although both VO_2 max and AT are often used to express cardiovascular fitness, the two measurements appear limited by different mechanisms by which VO_2 max is controlled by maximal cardiac output, while skeletal muscle metabolism plays more of a role in determining submaximal exercise performance (Gollnick et al., 1982; Saltin et al., 1976). A further development of this concept in a practical context would be the need for specific training programmes for both the body's central and peripheral components of endurance performance.

Following the observation that both LT and V_T were significantly improved when players were in the highly trained state, it would appear that either method would be useful in describing AT. Although LT does not cause V_T, the two are undoubtedly related and the close similarity between O_2 consumption in the two threshold points supports this observation. A greater difference was evident between tests when using LT, however, the attraction of being able to identify a threshold point without utilising an invasive procedure enhances the potential application of V_T.

From Test 1 to Test 2, the percentage of LT and V_T to VO_2 max had increased to 86 and 85% respectively, which although high, is not exceptional when compared with elite endurance athletes (Forenbach et al., 1987; Svendenhag and Sjodin, 1985). Either measurement has the advantage over VO_2 max of being submaximal and would consequently provide less disturbance to an organized training schedule. If the coach or athlete knows the physiological meaning of AT and the associated consequences of intracellular acidosis, he can apply this knowledge to his training.

CONCLUSION

In conclusion, although VO_2 max may provide a useful indication of the aerobic capacity of elite soccer players it's use is limited in the ongoing process of monitoring changes in training state and the maximal effort required may not be appropriate for repeated testing over the competitive season. Submaximal LT or V_T may identify changes in aerobic conditioning, however, tests more specifically related to soccer could be expected to provide useful information in addition to LT or V_T (Edwards et al., 2003).

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