ORIGINAL ARTICLE

Lactate threshold responses to a season of professional British youth soccer

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Objective: To examine the changes in aerobic endurance performance of professional youth soccer players throughout the soccer season.

Methods: Nine youth soccer players were tested at six different time points throughout the soccer season by sub-maximal blood lactate assessment, using an incremental treadmill protocol. Whole blood lactate concentration and heart frequency (Hf) were determined at each exercise stage. Running velocities at the first lactate inflection point (v-T_{lac}) and at a blood lactate concentration of 4 mmol l^{-1} (v-4mM) were determined.

Results: Running velocity at the two lactate thresholds increased from the start of pre-season training to the early weeks of the competitive season, from 11.67 (0.29) to 12.96 (0.28) km h^{-1} for v-T_{lac}, and from 13.62 (0.25) to 14.67 (0.24) km h^{-1} for v-4mM ($p<0.001$). However, v-T_{lac} and v-4mM when expressed relative to maximum heart frequency (Hf_{max}) remained unchanged. The Hf to blood lactate concentration relationship was unchanged after the pre-season training period. The two expressions of lactate threshold did not reveal differences between each other.

Conclusion: Running velocity at v-T_{lac} and v-4mM increased significantly over the pre-season period, but v-T_{lac} and v-4mM were unchanged when expressed relative to Hf_{max}. This finding may indicate that increased endurance performance may be mainly attributable to alterations in Vo_{2max}. Although lactate assessment of soccer players is useful for determining endurance training adaptations in soccer players, additional assessment of the other two determinants of endurance performance (Vo_{2max} and running economy) may provide more useful information for determining physiological adaptations resulting from soccer training and training interventions.

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A number of fitness components have been identified as being important for the soccer player, including aerobic fitness, anaerobic fitness components (such as jumping ability and acceleration), strength, and flexibility.[1] The importance of aerobic fitness in professional soccer is highlighted by the facts that elite players cover 10–12 km during a competitive match at an average intensity of around 75% of their maximal oxygen uptake (Vo_{2max}) and that the aerobic system contributes approximately 90% of the total energy cost of match play.[2 3] High aerobic endurance performance has the potential to optimise soccer performance by enhancing recovery from high intensity intermittent bouts during match play, thereby contributing to the ability to sustain a high work rate throughout a full competitive match.[3 4] Thus, it is of importance to monitor the aerobic endurance performance of professional soccer players periodically throughout the soccer season.

Sub-maximal blood lactate assessment is a useful tool for detecting changes in endurance fitness,[5] with lactate threshold determination possibly being a more sensitive indicator of aerobic endurance performance than Vo_{2max}.[6–8] A higher lactate threshold theoretically means that a player could maintain a higher average intensity during a soccer match without accumulation of lactate.[3 9] Sub-maximal blood lactate assessment has been previously utilised by researchers when assessing the aerobic fitness of soccer players. Blood lactate assessment has been used to monitor aerobic fitness changes across a pre-season and in-season intermission period with professional Danish players,[2] and throughout a soccer season with professional English players,[10 11] across two soccer seasons with an elite Scottish soccer team,[12] and over a 3 year period with international female Danish players.[13]

The aims of this study were: (a) to examine the changes in sub-maximal blood lactate measurement of professional Scottish youth soccer players throughout the soccer season; (b) to test whether two different established methods for determining lactate thresholds correlate; and (c) to discuss the possible limitations of lactate threshold measurements in terms of discrimination between the factors contributing to aerobic endurance performance.

METHODS

Subjects

Thirty seven male youth professional soccer players with a mean (standard deviation, SD) age of 18.3 (0.3) years participated in this study. The players were required to sign a consent form and medical questionnaire after being informed of the procedures and risks involved before each assessment. The study was approved by the local ethics committee.

The study involved the players being assessed by sub-maximal blood lactate measurement on a treadmill at six time points throughout a soccer season: July (beginning of pre-season training); October; December; January; April; and June (end of soccer season). Data collected from players who missed one or more testing time points were excluded from the analysis. Nine players were available at all six testing time points and their physical characteristics are presented in table 1.

Abbreviations: FBLC, fixed blood lactate concentration; Hf, heart frequency; SD, standard deviation

Table 1 Physical characteristics of players (n = 9)

Age (years)	Height (cm)	Mass (kg)	Hf_{max} (beats min^{-1})
17.8 (0.2)	177.7 (1.1)	71.3 (3.2)	204.9 (1.6)

Values are mean (SD). Hf, heart frequency.

Testing

Each player performed a 5 min warm up on a Woodway ERGO ES2 treadmill (Cranlea, Birmingham, UK) at a velocity that elicited a heart frequency (Hf) of approximately 60% of estimated maximum (Hf_{max}). Thereafter, the subjects carried out stretching exercises of their own choice for 5 min. The test protocol consisted of individual 4 min exercise stages, with a 0.5 km h^{-1} increase in treadmill velocity until test termination. Each assessment started at a treadmill velocity that elicited a Hf of approximately 60% Hf_{max}. The test was terminated when the blood lactate concentration of the exercising subject exceeded 4 mmol l^{-1} or by the subject's own request. Hf was recorded at 3 min 45 s (Polar Accurex, Kempele, Finland). Blood samples were withdrawn from the subject's thumb at the end of each exercise stage by pin prick and were analysed for whole blood lactate concentration using an Analox GM7 analyser (Analox Instruments, London, UK). Treadmill inclination was set at 0% throughout the assessment, and velocity was validated with an odometer (Trumeter, Radcliffe, UK).

Lactate threshold determination

Lactate threshold running velocity (v-T_{lac}) was identified as the first significant elevation of blood lactate above resting levels.[14] In order to achieve objectivity, a two phase linear regression model[15] was used in order to estimate the inflection point of the lactate profile ''curve'' (corresponding to the v-T_{lac}). A log transformation to both the running velocity and blood lactate concentration was applied in an attempt to gain a better estimate of the lactate threshold.[16] Running velocity at a lactate concentration of 4 mmol l^{-1} (v-4mM) was calculated by linear extrapolation, using the lactate concentration points at the running velocities directly before and after attainment of 4 mmol l^{-1}.

Maximum heart frequency determination

Hf_{max} for the players were determined from the highest Hf recorded (Polar Accurex) from a 20 m multi-stage shuttle test[17] completed before and after the pre-season training period.

Training

A diary of squad training throughout the full season was obtained. A typical training week consisted of four to seven training sessions and one/two soccer matches per week (table 2).

Table 2 Overview soccer season training of the professional youth players

	Average hours training per week			
	Pre-season–Oct	Oct–Dec	Jan–Mar	Mar–Jun
Warm up	1.67	2.17	1.67	2.17
Stretching	1.5	1	1	1
Endurance running	3	1.5	1	0.5
Small sided games	2.5	1.75	2	1.25
Technical training	1	1.5	1.5	1
Strength training	1	1	1	0.5
Match play	1.5	1.5	2.25	3
Total	12.2	10.4	10.4	9.4

Statistical analysis

There were always some players unavailable at each testing time point, sometimes because of illness or international youth team commitments, but mostly because of injury. Therefore, considerable imbalance in the data in terms of missing values over the six testing time points occurred. Nine players had complete data and all results refer to this sub-set. A repeated measures ANOVA (with Greenhouse-Geisser corrections as necessary) was used to determine any significant changes in mean v-T_{lac} and v-4mM across the soccer season. Pearson's product-moment correlation was used to determine the relationships between variables. Data are expressed as means (SD).

RESULTS

Mean running velocity at v-T_{lac} and v-4mM increased from the start of the pre-season training to October (fig 1), resulting in significantly lower lactate levels at each measured running velocity ($p<0.001$) (fig 2). Mean running velocity at both lactate threshold markers increased from the start of pre-season training to October: 11.67 (0.29) to 12.96 (0.28) km h^{-1} for v-T_{lac} and 13.62 (0.25) to 14.67 (0.24) km h^{-1} for v-4mM ($p<0.001$). There are no significant differences in lactate responses to increased running velocity at any of the other testing time points.

When lactate values are plotted against Hf at the running velocities tested from pre-season to October, that is, the period showing significant changes in lactate response, no significant differences in the lactate concentration to Hf relationship were found (fig 3). Hf_{max} was unchanged across this time period, and subsequently v-T_{lac} and v-4mM expressed as $\%Hf_{max}$ were unchanged.

The two different methods for determining lactate threshold were significantly correlated. Correlation between v-T_{lac} and v-4mM was $r = 0.87$ ($p<0.001$). A significant correlation was also observed between Hf at v-T_{lac} and v-4mM ($r = 0.82$, $p<0.001$).

DISCUSSION

The main conclusion of this study is that aerobic endurance performance increased significantly from the start of the pre-season training period to the early weeks of the competitive playing season (October), as evidenced by significant increases in mean running velocity at both v-T_{lac} and v-4mM. This change is probably mainly attributable to the fact that the players returned to pre-season training in a detrained state, due to a summer intermission break of

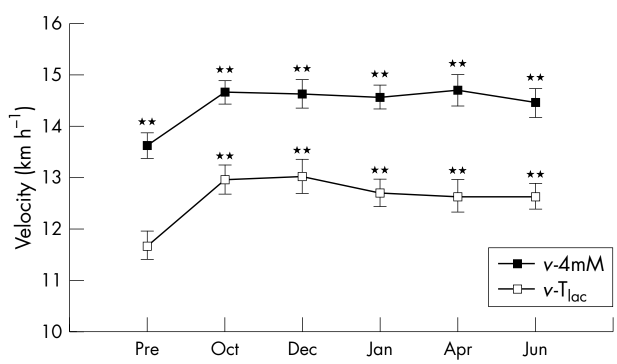

Figure 1 Running velocity at lactate thresholds v-T_{lac} and v-4mM at the six different time points using a flat treadmill. **Significantly different from pre-season ($p<0.001$).

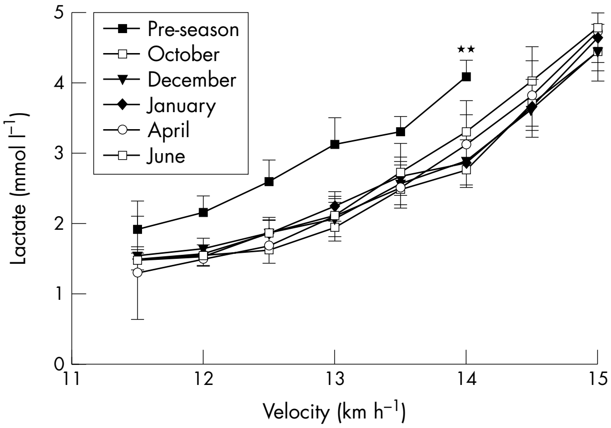

Figure 2 Lactate levels at fixed running velocities on a flat treadmill at different testing time points throughout the soccer season. **Significantly different from all other time points ($p<0.001$).

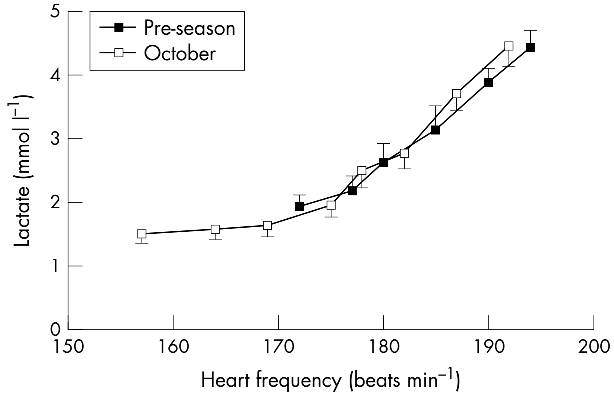

Figure 3 Lactate levels as a function of heart frequency before and after pre-season training.

approximately 5 weeks duration. During the summer break the players were not involved in any structured aerobic fitness programme. Amigo *et al*[18] investigated the effects of the summer intermission on amateur soccer players who had been training for 11 months prior to the summer break and found significant decrements in the cross-sectional area of slow twitch and fast twitch fibres, and a significant decrement in the activities of aerobic enzymes.

The finding of an improved aerobic endurance performance over the pre-season preparation period is supported by the studies of Bangsbo[2] and Brady *et al*,[12] although Dunbar[11] reported no change in fixed blood lactate concentrations (FBLC) of 2 and 3 mmol l^{-1} over the pre-season period in a squad of English professional players. Bangsbo[2] tested elite soccer players using sub-maximal blood lactate and $\dot{V}O_{2max}$ assessment before and after a 5 week pre-season training period. At the end of the training period, $\dot{V}O_{2max}$ was only slightly higher than before the pre-season, but blood lactate concentrations during sub-maximal running were significantly lower, resulting in a 25% higher mean running velocity at an FBLC of 3 mmol l^{-1}, similar to the findings in the present study. Another study by Bangsbo[2] involved quantifying aerobic fitness changes in a Danish soccer team over a 7 week in-season intermission period. Mean $\dot{V}O_{2max}$ increased from 58.6 to 60.3 ml kg^{-1} min^{-1} across the preparation period and the mean blood lactate concentration during sub-maximal treadmill running (9 to 13 km h^{-1}) was found to be significantly lower at all the treadmill velocities. The changes in blood lactate concentrations of approximately 1 mmol l^{-1} at the same running velocity were identical to the improvements in this study.

A change in lactate threshold can be expressed relative to $\dot{V}O_{2max}$ or to Hf_{max}. In this study, we have presented lactate values relative to Hf (fig 3), indicating that there is no significant change in relative lactate threshold from the start of pre-season training to the early days of the competitive season (October), although there are clearly higher running velocities at the same lactate values in October when compared to pre-season (fig 2). These findings are in line with those of Helgerud *et al*[3] who showed no change in lactate threshold (relative to Hf_{max} and $\dot{V}O_{2max}$) when significantly elevating $\dot{V}O_{2max}$ after an endurance intervention period in soccer players. Although running velocity increased by 16% from 11 to 13.5 km h^{-1} ($p<0.05$) in the study of Helgerud *et al*,[3] lactate threshold expressed relative to Hf_{max} (87.4 (2.3) to 87.6 (2.4) %Hf_{max}) and $\dot{V}O_{2max}$ (82.4 (3.1) to 86.3 (2.1) %$\dot{V}O_{2max}$) was not significantly changed. It seems that lactate threshold changes in tandem with $\dot{V}O_{2max}$ in soccer players, and in terms of %Hf_{max} and %$\dot{V}O_{2max}$ the adaptability seems to be minor (<5%).[3 10 19]

Reproducibility of the v-T_{lac} and v-4mM using the same incremental treadmill protocol as in this study has been investigated recently[20] with no differences in reproducibility found between v-T_{lac} and v-4mM. As can also be observed in fig 1, any fixed lactate value between 2 and 4 mmol l^{-1} would reveal similar changes, and may be used for lactate assessment of soccer players.

Pate and Kriska[21] have described a model that incorporates the three major factors accounting for inter-individual variance in aerobic endurance performance, namely $\dot{V}O_{2max}$, lactate threshold, and work economy, with numerous published studies supporting this model.[9 22 23] Thus, the model serves as a useful framework for comprehensive examination of the effects of aerobic training on endurance performance. Since lactate threshold in relative terms does not change in this study, the explanation for improved aerobic performance may be attributable to changes in $\dot{V}O_{2max}$ and/or running economy (C_R).

$\dot{V}O_{2max}$ has been suggested to be a very important factor for determining success in an aerobic endurance sport.[24 25] Previous studies have demonstrated a significant relationship between $\dot{V}O_{2max}$ and distance covered during soccer match play[3 26 27] and number of sprints attempted.[26] No correlation, however, has been documented between %$\dot{V}O_{2max}$ at lactate threshold and performance during soccer match play, although a significant correlation has been found between v-4mM and distance covered by soccer referees ($r = 0.73$, $p<0.05$).[28] An improved $\dot{V}O_{2max}$ will lower the lactate concentration and Hf at a standardised running velocity, similar to what has been shown in this study. The improvements in running velocity at a standard lactate level and reduced Hf of approximately 10 beats min^{-1} at a fixed speed after the pre-season preparation period may indicate an improved $\dot{V}O_{2max}$ in the range of 3–5 ml kg^{-1} min^{-1}.[9] Even though $\dot{V}O_{2max}$ was not measured in this study, the most plausible explanation for the improvements may be related to an improved $\dot{V}O_{2max}$.

Improvement in endurance performance in this study may also be attributed to improvements in C_R. Helgerud *et al*[3] observed improvement in C_R of soccer players when using a two-sessions-a-week specific running intervention. Hoff and Helgerud[3 29] have also demonstrated a 5% improvement in C_R in soccer players when using a maximal strength training intervention. In the present study, however, no strength training in terms of heavy neuromuscular weight training was employed. C_R was not measured in the present study, but it is plausible that C_R may have changed across the season.

This study has shown that aerobic endurance performance of professional youth soccer players increased significantly over the pre-season training period, but did not change significantly during the competitive season. The findings of the present study echo the findings of the historical study of Thomas and Reilly[30] who reported that endurance fitness increased during the first third of the season and remained relatively stable throughout the course of the competitive season. The findings of the present study are in contrast to those of Brady *et al*[12] who demonstrated deterioration of the player's endurance levels over the course of the competitive season following the achievement of peak fitness at the end of the pre-season training period. The authors suggested that the decrement of aerobic fitness levels towards the end of the season may have been a consequence of coaches "scaling down" training in order to save the players' efforts for competition. Time normally allocated for soccer training may be reduced as the soccer season progresses, due to an accumulation of competitive matches. A backlog of previously postponed matches and more matches in the latter stages of cup competitions for successful teams may decrease weekly time available for endurance training, especially in the last few months of the season. The endurance fitness gains manifested from the pre-season preparation period were successfully maintained for the remainder of the season in the present study. This may indicate that the physiological load of competing in two competitive soccer matches per week in conjunction with the training regime documented in the present study may be sufficient for maintaining endurance fitness levels during the in-season period. This means that it is important that soccer players who are not participating regularly in competitive matches perform additional individual endurance training to maintain, or even increase, their endurance levels.[31] Soccer coaches are challenged to employ training strategies that increase the aerobic endurance performance of soccer players during the competitive in-season period, whilst not increasing the risk of over-reaching and over-training or promoting fatigue on match days that would adversely affect performance.

Although 37 players were available for testing throughout the season, only nine players were available for testing at all six testing time points. Three players left the squad during the study, and seven players were unavailable at one or more of the testing time points due to international commitments or illness. Therefore, most data collected in this study were excluded due to 18 players (49% of the squad) being injured at the time of one or more of the testing time points. Although this may seem a high occurrence of injury, studies by Hawkins *et al*[32] and Woods *et al*[33–35] have highlighted the high incidence of injury in professional soccer, especially in younger age groups.[33]

Conclusions

This study has shown that the endurance fitness of the soccer players increased over the pre-season to the early weeks of the competitive season, and was unchanged for the remainder of the season, in line with earlier findings. The results of this study also indicate that sub-maximal blood lactate assessment of soccer players can be used as an indicator of change in soccer players' endurance performance levels over a specified time period. This study has shown that any fixed blood lactate level between 2 and 4 mmol l^{-1} is appropriate during lactate assessment to determine sub-maximal responses to change in aerobic endurance levels. Since lactate threshold alterations appear to change in tandem with Vo_{2max} for soccer players, and also because C_R of soccer players may be altered by specific endurance running and strength training interventions, it is suggested that Vo_{2max} and C_R of professional soccer players should be primarily assessed.

What is already known on this topic

Aerobic endurance performance of soccer players has been shown to fluctuate across the soccer season. Sub-maximal lactate assessment has been previously used for monitoring changes in aerobic fitness levels of soccer players.

What this study adds

Fixed blood lactate levels between 2 and 4 mmol l^{-1} may be used as an indicator of aerobic endurance performance for soccer players. However, since lactate threshold does not change in relative terms after soccer training, other assessments such as Vo_{2max} and running economy may be more appropriate.

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