

Research article

Season-to-season variations of physiological fitness within a squad of professional male soccer players

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Abstract

The purpose of this study was to examine season-to-season variations in physiological fitness parameters among a 1st team squad of professional adult male soccer players for the confirmatory purposes of identifying normative responses (immediately prior to pre-season training (PPS), mid-season (MID), and end-of-season (EOS)). Test-retest data were collected from a student population on the primary dependent variables of anaerobic threshold (AT) and maximal aerobic power (VO₂ max) to define meaningful measurement change in excess of test-retest technical error between test-to-test performances. Participants from a pool of 42 professional soccer players were tested over a set sequence of tests during the 3-year period: 1) basic anthropometry, 2) countermovement jump (CMJ) tests 3) a combined AT and VO₂ max test. Over the 3-year period there were no test-to-test changes in mean VO₂ max performance exceeding pre-defined limits of test agreement (mean of eight measures: 61.6 ± 0.6 ml·kg⁻¹·min⁻¹). In contrast, VO₂ at AT was significantly higher at the MID test occasion in seasons 2 (+4.8%; p = 0.04, p < 0.05) and 3 (+6.8%; p = 0.03, p < 0.05). The CMJ tests showed a test-to-test improvement of 6.3% (best of 3 jumps) (p = 0.03, p < 0.05) and 10.3% (20-s sustained jumping test) (p = 0.007, p < 0.01) between PPS2 and MID2 and thereafter remained stable. Anthropometrics were unaffected. In summary, despite some personnel changes in the elite cohort between test-to-test occasions, VO₂ max values did not vary significantly over the study which supports previous short-term observations suggesting a general 'elite' threshold of 60 ml·kg⁻¹·min⁻¹. Interestingly, AT significantly varied where VO₂ max was stable and these variations also coincided with on- and off-seasons suggesting that AT is a better indication of acute training state than VO₂ max.

Key words: Aerobic power, anaerobic threshold, countermovement jump, elite athletes.

Introduction

There have been numerous studies conducted which have evaluated the physiological characteristics of soccer players (e.g. Brewer and Davis, 1992; Reilly et al., 2000; Stølen et al., 2005) and the physical demands of playing the game (e.g. Reilly and Thomas, 1976; Edwards and Clark, 2006; Krstrup et al., 2003). However, there are few longitudinal reports on adult male professional soccer players (Casajús, 2001; Edwards et al., 2003a; Koutedakis, 1995; Reilly and Thomas, 1980) and no studies have

reported normative data from a pool of elite players across more than one season. The absence of these basic data is problematic when establishing appropriate 'threshold' levels of fitness among homogenous groups of well-trained professional soccer players. This omission from the current scientific literature is probably due to a combination of factors, such as a reluctance of professional teams to release performance test results to the scientific community, issues surrounding the absence of comparative control groups, but also the limited opportunities for repeated testing of the same players in well-controlled laboratory conditions during the competitive season (Reilly, 2005).

The maintenance of fitness during a season is a key target for every team (Koutedakis, 1995) but this is a complex process reflecting the diverse physical demands of the game. The mean intensity of exercise during a soccer match has been estimated to approximate ~80% of maximal aerobic power (VO₂ max) (Reilly et al., 2000; Stølen et al., 2005) and this intensity broadly resembles typical values of anaerobic threshold measurements in professional players (Edwards et al., 2003a). The association between VO₂ max and distance covered during match play (Reilly and Thomas, 1976) has further been used to suggest that the predominant metabolic pathway during professional soccer is aerobic (Bangsbo, 1994). However, although elite soccer performance is, in part, dependent on a high cardiopulmonary fitness, VO₂ max has not been correlated with high-intensity exercise during a game (Krustrup et al., 2003).

Several researchers have proposed that a VO₂ max of ~60 ml·kg⁻¹·min⁻¹ is a minimal threshold for elite professional male soccer players (Helgerud et al., 2001; Reilly et al., 2000), but there is currently a lack of elite level normative data to support this observation and beyond the identification of a minimum 'elite performer' threshold, it is unclear whether cardiopulmonary fitness is of direct value to performance. In addition, it has yet to be established whether or not this variable is susceptible to seasonal variations among a homogenous population of elite players where changes in personnel are common, thus affecting the levelness of fitness among the squad; and also whether or not it is influenced both by long- and short-term factors such as: on- and off-seasons, training methods, frequency of match-play, and injuries.

In situations where players are well-matched for cardiovascular fitness it is likely that other match-related factors such as sprinting and jumping performances are

important. Studies of motion-analysis in match-play suggest that almost all (~96%) sprints during games are <30-m and the majority of these are <10-m (Reilly and Thomas, 1976; Bangsbo, 1994). However, few studies of professional players have reported longitudinal measures of explosive capability (Casajús, 2001; Reilly and Thomas, 1980). One study (Reilly and Thomas, 1980) demonstrated an improvement in vertical jump performance at the beginning of the competitive season but reported no further change. This suggests that anaerobic characteristics are well maintained over the course of the season, although the lack of substantial confirmatory data from elite populations to support seasonal variations in either aerobic or anaerobic characteristics remains problematic.

The repeated measurements of fitness variables in professional players can be heavily influenced by participation rates that are compromised by injuries, match commitments, inter-club transfers, and general player availability. This is a common difficulty where the objectives of the researcher are of secondary importance to the professional team. For example, Casajús (2001) reported well controlled measurements of physiological fitness from Spanish League players on two occasions between September (following 5 weeks of training), and February (mid-season) and observed a non-meaningful change of +1.7% in maximal aerobic power. However, of the 16 players who began that study, only 12 were available for testing on the second occasion. Due to this high level of participant attrition, no other studies have reported mean test responses in elite players over an extended period, probably due to similar difficulties which are clearly exacerbated over time. This omission from the scientific literature poses substantial problems for investigators seeking to establish normative physiological responses in relatively homogenous groups.

The purpose of this study is to examine the season-to-season variations of physiological fitness among professional adult male soccer players over a 3-year period utilising a more frequent and repetitive view of seasonal variation than reported previously (immediately prior to pre-season training, mid-season, and end-of-season) and, where possible, identifying meaningful performance changes in the context of pre-defined limits of agreement derived from empirical test-retest data collected in our laboratory.

Methods

Subjects

All participants who took part in this study provided written informed consent in accordance with the Declaration of Helsinki and the requirements of the Ethics Committee of Reading University, UK.

Test-retest reliability of the cardiopulmonary fitness test protocol

It was not possible to include a comparative matched control group in this longitudinal study of fitness measurements in professional soccer players. In consideration of this, the test-retest reliability of the primary cardiovascular exercise protocol was pre-defined using a convenience sample so to be able to subsequently infer meaningful change in performance over that of any variation in measurement error.

Test-retest data of maximal aerobic power (VO_2 max) and anaerobic threshold (AT) were collected from 20 male undergraduate students (20 ± 1.8 years; 77.6 ± 4.7 kg) (Table 1) who all performed the same laboratory test on two occasions separated by one week in similar laboratory conditions ($\sim 18^\circ\text{C}$) and at similar times of the day. The information derived from these tests was used for the purpose of identifying pre-defined limits of test-retest agreement (Bland and Altman, 1986) for the test procedures. By using this process, acceptable reliability was set at the minimal positive and negative limits which encompassed all of the 20 observations. Subsequent seasonal variations between the repeated performances of the soccer players could thereafter be ascribed to either technical/trivial variability (if they fell within the pre-defined limits of agreement, or biological/meaningful variability (if they fell outside of the pre-defined limits of agreement).

Professional soccer players

Over the three year period, a pool of 42 male professional 1st team soccer players (age: 25 ± 3.5 years, stature: 1.78 ± 0.3 m, body mass: 79.4 ± 1.6 kg) from a single English Championship Club performed the experimental protocols. Only players free of injury and in full training were tested as part of the study. During the three year period, some changes in personnel were observed on test-to-test occasions due to both temporary and permanent inter-club transfers, player availability, and also short- and long-term injuries.

Test series

The same sequence of tests were conducted on eight occasions over 3-years in the same order and, where possible, at the same time of day in a temperature controlled ($\sim 18^\circ\text{C}$) exercise laboratory. Despite some changes in personnel, the cohort was a homogenous group of outfield soccer players and the physical characteristics of the players at each of the repeated measures are shown in Table 2.

Over the three seasons (1: 2001-2002, 2: 2002-2003, 3: 2003-2004) the same sequence of tests was performed on eight occasions: 1) immediately prior to pre-season training (PPS), 2) mid-season (MID), and 3) end

Table 1. The test-retest reliability of the combined test procedure for the estimation of anaerobic threshold (AT) and maximal aerobic power (VO_2 max). Results from test 1 (t1) and test 2 (t2) are reported from the 20 recreationally active subjects. These parameters were used to pre-define acceptable protocol limits of (error) agreement for the subsequent soccer observations. Results are expressed as mean (\pm SD).

VO_2 AT (t1) $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	VO_2 AT (t2) $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	VO_2 max (t1) $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	VO_2 max (t2) $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	CV %	CV %
34.1 (5.3)	33.9 (4.8)	49.5 (6.2)	49.7 (5.7)	4.6	3.4

VO_2 AT = oxygen uptake at anaerobic threshold. VO_2 max = maximal aerobic power. CV = Coefficient of variance.

Table 2. Physical characteristics of the professional soccer players at each of the eight test occasions. Results are expressed as mean (\pm SD).

Variable	Test occasion							
	PPS1 (n = 22)	EOS1 (n = 22)	PPS2 (n = 22)	MID2 (n = 14)	EOS2 (n = 17)	PPS3 (n = 13)	MID3 (n = 10)	EOS3 (n = 11)
Age (years)	26.0 (4.3)	27.0 (5.2)	25.0 (3.1)	24.0 (.05)	25.0 (3.8)	25.0 (3.4)	24.0 (3.1)	25.0 (3.2)
Stature (m)	1.79 (.07)	1.76 (.06)	1.79 (.05)	1.77 (.04)	1.76 (.04)	1.77 (.04)	1.76 (.04)	1.79 (.04)
Body mass (kg)	81.3 (9.9)	78.3 (9.1)	81.0 (9.7)	79.7 (5.3)	77.8 (7.2)	77.9 (4.3)	78.2 (6.5)	80.9 (5.1)
Fat (%)	12.6 (3.0)	11.6 (2.6)	12.8 (3.0)	11.6 (2.4)	11.5 (2.9)	11.8 (2.3)	11.5 (2.2)	11.1 (2.7)

PPS1-3 = Prior to pre-season, MID 2-3 = Mid-season, EOS 1-3 = End of season.

of season (EOS). No tests were conducted at the MID interval of season one due to heavy match commitments at that time.

The testing procedure followed the same order for each player: 1) baseline blood lactate evaluation 2) basic anthropometric evaluation 3) countermovement jump (CMJ) tests (best of 3 jumps and 20-s sustained jumping) 4) combination test of AT and VO_2 max.

Test procedures

Body composition was assessed by bioelectrical impedance (BIA) (Tanita TBF-551 Body composition scales). Participants were allowed $2\text{ml}\cdot\text{kg}^{-1}$ body mass of water in the hour preceding testing to standardize hydration (Edwards et al. 2007) and were asked to refrain from the consumption of alcohol and products containing caffeine in the 24 hr period preceding testing. Finally, all participants were requested to void as fully as possible prior to the evaluation of body composition.

Body mass and stature were determined using standard laboratory measurement techniques (Tanita TBF-551 scales, Tanita, Middlesex, UK; SECA 240 Stadiometer, Hamburg, Germany).

A 10-min warm up was completed by each player prior to the CMJ tests which included light jogging, specific mobility exercises and a stretching routine.

The CMJ was performed according to the Bosco method (Bosco et al., 1983), whereby the highest vertical jump (jump height in cm) and the longest flying time (time between take-off and landing) were recorded. The 'best' CMJ of three efforts was recorded and the subsequent mean of 20-s sustained CMJ effort was also recorded to ascertain whether fatigue might be a factor in jump performance. The apparatus consisted of a digital timer connected by a cable to a jump platform (NewTest version 2.0). The timer was triggered at take-off and then by the participant's feet at the moment of touchdown (Hoffman and Kang, 2002). The subject started from an upright standing position on the platform, and following the eccentric phase (corresponding to a semi squatting position), the participants jumped vertically without using arms to aid further height (arms remained at both sides, hands on the hip throughout the tests).

All participants completed the same combination test of AT and VO_2 max. 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 $4.03\text{ m}\cdot\text{s}^{-1}$. The test started with a warm up of 2-min at a walking pace of $0.97\text{ m}\cdot\text{s}^{-1}$ and was followed by 3-min at $2.78\text{ m}\cdot\text{s}^{-1}$ prior to the first stage of the test. The test was designed to enable the participants to reach aerobic steady

state within 3-min in each stage ($3.47, 3.61, 3.75, 3.89$ & $4.03\text{ m}\cdot\text{s}^{-1}$) with a further 30-s included in each stage for the collection of blood samples. During each 30-s period, participants were stationary before recommencing the test for the next 3-min stage. After the final 3-min stage at $4.03\text{ m}\cdot\text{s}^{-1}$ was completed, the incline of the treadmill was increased by 2% every minute until volitional fatigue as reported previously (Edwards et al., 2003a). Criteria from British Association of Sport and Exercise Sciences (1997) were used to ascertain whether or not maximal aerobic power had been attained.

For the purposes of accurate assessment of the AT, the mean of VO_2 at both 1) the speed at which the production of lactate began to surpass its clearance (Noakes, 1998) and 2) the ventilatory threshold (VCO_2/VO_2 measurements) were determined. AT was identified as the exercise induced VO_2 immediately preceding a $0.5\text{ mmol}\cdot\text{l}^{-1}$ increase in blood lactate concentration above the mean of two baseline values (Edwards et al., 2003a) and ventilatory threshold was identified by the V slope method, described by Beaver et al., (1986). These measures have been shown to be closely related using this protocol (Edwards et al., 2003a, Edwards and Cooke, 2004) and our experience in the laboratory support the combined approach for greater reliability in the measurement of AT (unpublished observations).

Blood sampling

Whole blood was sampled from a fingertip at rest prior to any testing. A small incision was made with a single use disposable lancet and capillary whole blood was collected into a $100\text{ }\mu\text{l}$ capillary tube (Becton Dickinson, New Jersey, USA). Thirty five μl of whole blood were immediately analysed for lactate concentration (Analox GM7 Analyser, Analox Instruments, London, UK) at rest, and at the conclusion of each incremental stage in the anaerobic threshold element of the aerobic test.

Statistical analyses

Analysis of the repeated measurement on all primary dependent variables was considered in relation to the previous observations by members of this research team concerning appropriate statistical use for repeated measures experimental models (Morton, 2005). On this basis, a general linear model ANOVA (MINITAB Inc, State College, PA) was used to compare seasonal variations in physiological fitness measures. Post-hoc Tukey tests of honest significant difference were applied to examine where differences existed. Statistical significance was accepted when $p < 0.05$. All results are expressed as means \pm unless otherwise stated.

The test-retest reliability of the cardiopulmonary

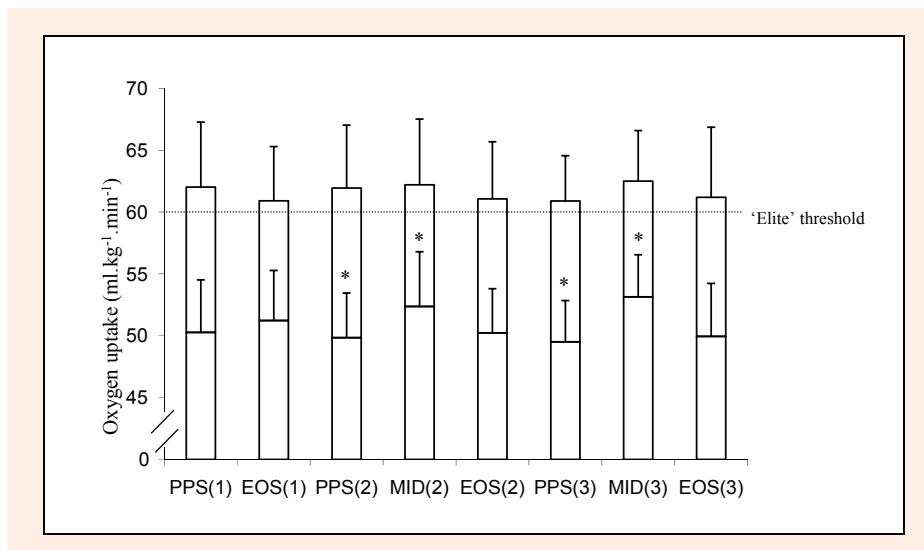


Figure 1. Oxygen uptake corresponding to both: maximal aerobic power (VO_2 max), and anaerobic threshold (AT) measurements across the eight test occasions. PPS 1-3 = Prior to pre-season, MID 2-3 = Mid-season, EOS 1-3 = End of season. * denotes $p < 0.05$ between PPS and MID measurements. No other measures were significantly different.

test was determined by calculating limits of agreement between two tests (Bland and Altman, 1986). For both maximal aerobic power and anaerobic threshold, individual differences between tests 1 and 2 were plotted against the mean difference on each measurement. Upper and lower limits of agreement were calculated as the minimum standard deviation from the mean difference that incorporated all 20 test-retest data sets. These upper and lower limits were subsequently used to reflect the statistical distinction between 'trivial/technical' effects i.e. within the likely test-retest limits, and 'meaningful/biological' performance change i.e. change in excess of the limits of variability. The coefficient of variation (CV) was expressed as a percentage and calculated as: $CV = 100 \times SD_{diff}/X$. The SD_{diff} indicated the standard deviation of the difference between the duplicate measurements, and X the mean reading of the measurements.

Results

Preliminary data: test-retest reliability of cardiopulmonary fitness test measurements

The upper and lower limits of agreement represent the maximal variance that encompassed all 20 test-retest results of both VO_2 max and AT (Table 1). The results of the test-retest reliability evaluation demonstrated a coefficient of variation of 3.4% for VO_2 max and 4.6% for AT. The observed limits of agreement for VO_2 max and AT protocols were then applied to the professional soccer data to evaluate whether any changes between consecutive measurements exceeded the pre-defined test (non-biological) error.

Cardiopulmonary fitness

The mean VO_2 max for each test occasion was in excess of the $60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ threshold (Figure 1) suggested by previous authors as a minimum threshold for elite soccer performers (Reilly et al., 2000; Stølen et al., 2005). There was variation between means across the consecutive test

occasions; however, none of these changes were statistically significant. Although the PPS sample mean was consistently the lowest of the VO_2 max measurements this was not statistically significant (Figure 1). The three year consecutive measures of VO_2 max were subsequently plotted against the pre-defined limits of agreement but none of the changes between test occasions were in excess of the pre-identified maximal limits attributed to measurement error (Figure 2a).

The measurements of AT followed a similar pattern to VO_2 max, however, statistical evaluation demonstrated that MID2 ($p = 0.04$) and MID3 ($p = 0.03$) were significantly higher than their respective PPS values (Figure 1). When plotted graphically utilising the pre-defined limits of agreement, the two largest gains in AT occurred between the pre-season and mid-season intervals (PPS2 – MID2 4.8% gain; PPS3 – MID3 6.8% gain) (Figure 2b). The largest negative change in AT occurred between MID3 and EOS3 (6.0% loss; $p=0.04$). As percentages of maximum, the highest at which AT was observed corresponded to MID2 (84.2%) and MID3 (85.2%) (Figure 1). The three PPS test occasions were the three lowest percentages of maximal aerobic power (PPS1: 80.5%, PPS2: 81.05%, and PPS3: 81.3%).

Countermovement jump (CMJ) performance tests

Mean 'best' CMJ performances improved significantly between PPS2 and MID2 ($p = 0.03$) and thereafter remained consistently higher than season one measurements (PPS1 and EOS1) until the final test occasion at EOS3 where the mean reverted to the magnitude of earlier observations (Figure 3a). The 20-s CMJ test showed a highly significant change in performance between PPS2 and MID2 ($p = 0.007$) and remained consistently elevated from this time irrespective of test occasion (Figure 3b).

Body mass and composition

Body mass did not change across the eight measurement occasions (Table 2). Mean body mass ranged from 77.8

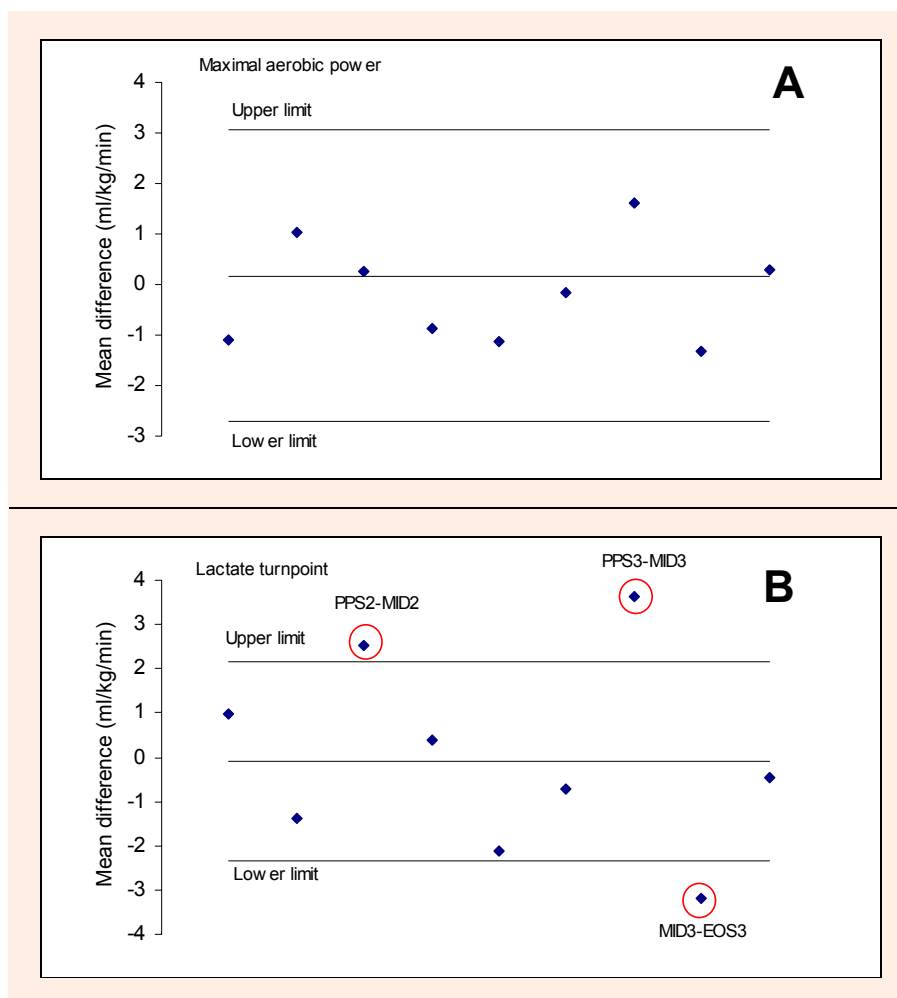


Figure 2. The test-to-test (PPS, MID, EOS) performance changes in maximal aerobic power (A) and anaerobic threshold (B) over the 3-year period. Performance changes within the pre-defined limits of agreement are considered trivial/technical variations, whereas those at or in excess of the limits are considered to be likely of biological significance. Significant changes are circled. PPS1-3 = Prior to pre-season, MID 2-3 = Mid season, EOS 1-3 = End of season.

Body mass and composition

Body mass did not change across the eight measurement occasions (Table 2). Mean body mass ranged from $77.8 \text{ kg} \pm 7.2$ (EOS2) and $81.3 \text{ kg} \pm 9.9$ (PPS1). Estimated percentage body fat also did not differ between test intervals and ranged from a low of $11.1\% \pm 2.7$ (EOS3) and a high of $12.8\% \pm 3.0$ (PPS2) (Table 2).

Discussion

The main observation of this study was that mean VO_2 max remained relatively stable among a homogenous population of elite soccer players and, in contrast to AT, did not change with different phases of the off- and on-seasons. Despite occasional test-to-test changes in personnel, the significant differences observed in AT measurements compared with VO_2 max (in the same players) clearly identifies AT as the more sensitive measure of training state. This observation confirms our previous observations from single test off- and on-season (Edwards et al. 2003a). Although VO_2 max and AT responded similarly over the duration of the study, the magnitude of change according to our criteria was only of biological

meaning in AT and these observations are supported by several generic laboratory investigations reporting increases in measures of the anaerobic threshold without parallel changes in VO_2 max (Denis et al., 1982; Edwards et al., 2003a; Henritze et al., 1985). Figure 2 illustrates the observation that AT demonstrated both significant changes and these were also in excess of the pre-set limits we identified as estimates of test-to-test measurement error. Our finding also supports the use of this technique to infer an element of control in elite athlete studies where it is not always possible to include a comparative control group. This may encourage others to report data from elite populations which would be of assistance to the further understanding of high quality performances across different sports.

Interestingly, the majority of mean performance changes in physiological and anthropometric variables occurred mid-season while there was a noticeable decline in some mean performance indicators towards the end of the three competitive seasons.

The observation of improved mid-season physiological performances is probably due to a number of inter-related factors. The typical English full-season is

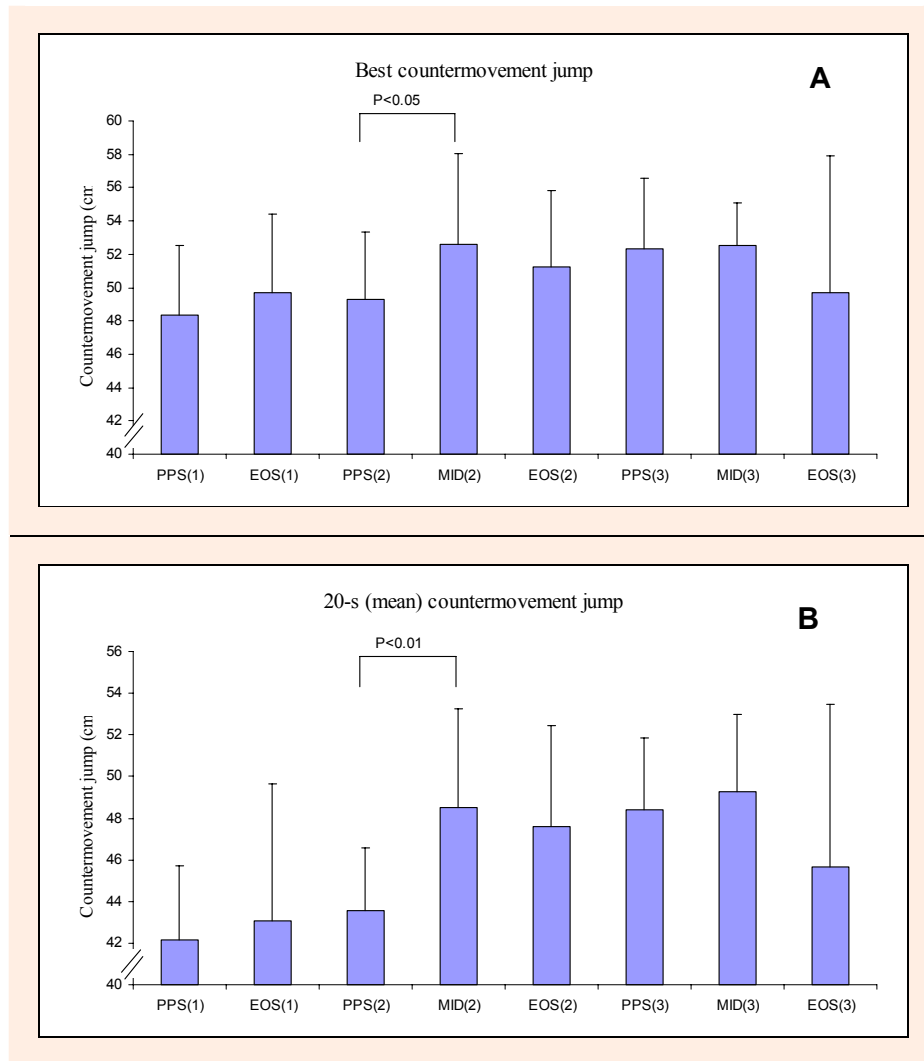


Figure 3. ‘Best’ (of three, **A**) and average (of 20-s, **B**) countermovement jump tests over the three year period. PPS1-3 = Prior to pre-season, MID 2-3 = Mid season, EOS 1-3 = End of season.

approximately 9-months and the mid-season measurements were taken after 5-months. At this stage, players involved in all games had usually completed ~25 competitive matches with a full season comprising ~55 matches (including all competitions). On this basis, the congestion of matches in the latter stages of the season may have negatively contributed to the test performances. In addition, the accumulative effect of minor injuries, reduced opportunities for aerobic conditioning training, and general fatigue could all be factors reducing test performances at that test occasion.

The mean VO_2 max test performance across all eight test intervals ($61.6 \pm 0.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) confirms earlier comments suggesting $60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ as a minimal ‘elite’ threshold (Helgerud et al., 2001; Reilly et al., 2000). However, the stability of this measure in comparison to AT across different stages of off- and on-seasons questions the relevance of repeated measurement of VO_2 max beyond the broad identification of aerobic capability in the tested cohort. In support of this statement, studies of soccer players have not tended to differentiate between adult players of differing standard (e.g. Brewer and Davis, 1992; Edwards et al., 2003b), nor been correlated with high-intensity exercise during match-play (Krustrup et al.,

2003), nor previously identified change between the on- and off-season in elite adult soccer players (Edwards et al., 2003a). This is consistent with the observation of a high genetic contribution to VO_2 max performance, thus probably restricting the potential for improvement (Bouchard et al., 1992), especially in elite athletes with already well-developed exercise capacities. Nevertheless, a previous study demonstrated significant improvements in the VO_2 max test performances of elite youth players as a consequence of specific aerobic training (Helgerud et al., 2001) but it is likely that those gains are probably, in part, attributable to maturation.

The percentages of VO_2 max at which AT occurred, which although reasonably high, are in agreement with previous observations (Edwards et al., 2003a, Helgerud et al., 2001; McMillan et al., 2005). As such, it is likely that there remains greater scope for AT to change in accordance with seasonal variations in the fitness of elite adult male players. A recent study of lactate thresholds in professional youth players (McMillan et al., 2005) also showed this was the case in that group. However, the test-retest reliability element of this study conducted among the student volunteers demonstrated a greater CV for AT (4.6%) compared with VO_2 max (3.4%) indicating that

although AT is useful, it remains appreciably more complex to accurately quantify. Although the variability of the measurements in our study were reasonably small, the subjective intra-observer and inter-observer reliability and reproducibility of ventilatory and lactate thresholds has previously been questioned (Gladden et al., 1985; Yeh et al., 1983). This is due to the complexities of identifying a sudden advance in lactate production when more commonly, lactate increases proportionally with the increased exercise intensity or power output (Allen et al., 1985; Myers and Ashley, 1997). Therefore, a combined assessment incorporating ventilatory variables to produce a mean VO_2 at AT is, in our opinion, preferable so as to obtain a more accurate measurement which can be observed via the relatively low CV (4.6%) reported in this study.

It seems likely that, although both AT and VO_2 max are related as measures of cardiopulmonary fitness, the two measurements are probably limited by different physiological mechanisms (Myers and Ashley, 1997). Considerable debate exists on the mechanisms limiting VO_2 max test performance (Bassett and Howley, 2000; Noakes, 1998); however, it is beyond the scope of this study to examine the causal factors limiting both VO_2 max and AT.

The ability to achieve a high standard of jumping performance is clearly related to activities during soccer match-play (Reilly and Thomas, 1976) and a previous study reported a close relationship between vertical jump height and performance in a soccer league (Arnason et al., 2004). The CMJ performances in this study (Figures 3a and 3b) were less than those previously reported in elite male volleyball players (CMJ: $54.3 \pm 4.6\text{cm}$) (Forthomme et al., 2005) but compared reasonably well with results from soccer players reported using similar protocols ($43.5 - 61.0\text{cm}$) (Stølen et al., 2005). The performances were well maintained over the 20-s trials (mean of eight trials: $46.0 \pm 0.3\text{cm}$) and qualitative observations from our laboratory support the use of CMJ tests in examining inter-individual jumping characteristics which showed clear differences between junior performers and the elite 1st team squad (unpublished observations). The 1st team squad improved CMJ significantly from the 1st season ($p < 0.05$) and maintained this stable performance thereafter. This is probably due to a training effect which was most evident in the 20-s test whereby contraction of the antagonist muscle groups was probably reduced, allowing for a greater coordination of these muscle groups so as to produce a more powerful and effective series of jumps (Schmidtbleicher et al., 1988).

Anthropometrics are also important in preparing for optimal performance in soccer (Reilly et al., 2000) as excessive adipose tissue acts as dead weight in activities where the body mass must be repeatedly lifted against gravity during locomotion and jumping (Reilly, 1996). Although the examination of anthropometrics was clearly basic in this study, previous estimates of fat values have ranged between 7.9% and 19.3% (White et al., 1988), while ~11% seems broadly normal for elite players (Ostojic, 2003; Rienzi et al., 2000; Rico-Sanz, 1998). The percentage body fat of players in our investigations are similar to those reported elsewhere (mean of eight tests:

11.8% in this study); however, the method of collection in this study was BIA and the greater technical error common to this method may explain why significant associations were not evident between % fat and the main outcome measures.

Reilly (1990) also reported an overall mean body mass of $74.0 \pm 1.6\text{ kg}$ for nine English professional squads and the eight mean body masses in this study are higher than those; however, this may in part be attributable to the greater mean height of our players ($1.78 \pm 0.26\text{m}$) while probably also reflecting gradual changes in anthropometrics of professional players between ~1990 – 2004.

Conclusion

In conclusion, this study is, to our knowledge, the first report of inter-seasonal variations among the physiological fitness parameters of adult male professional soccer players. The findings demonstrated that VO_2 max test performances were reasonably stable when measured across off- and on-seasons as all test-to-test changes were within the pre-defined limits of agreement indicating that variation was trivial. This appears to confirm our earlier observations (Edwards et al., 2003a) but was in contrast to several measures of AT which demonstrated significant change of biological meaning according to both the pre-defined limits of agreement and ANOVA analysis. Interestingly, the optimal mean test responses of the soccer players in this study generally coincided with the mid-season measurements where significant gains in several fitness indices were consistently observed. This presumably reflects enhanced motivation, and the avoidance of accumulative fatigue that may be prevalent at the end of season. However, although players were drawn from the same squad, some changes in player personnel between test-to-test measurements may have contributed to the observations in this study. Consequently, additional confirmatory studies are required to further support these findings.

References

- Allen, W.K., Seals, D.R., Hurley, B.F., Ehsani, A.A. and Hagberg, J.M. (1985) Lactate threshold and distance running performance in young and older endurance athletes. *Journal of Applied Physiology* **58**, 1281-1284.
- Arnason, A., Sigurdsson, S.B., Gudmundsson, A., Holme, I., Engebretsen, L. and Bahr, R. (2004) Physical fitness, injuries, and team performance in soccer. *Medicine and Science in Sports and Exercise* **36**, 278-285.
- Bangsbo, J. (1994) Physiological demands of soccer. In: *Football (Soccer)*. Ed: Ekblom, B. London: Blackwell Scientific. 43-59.
- Bassett, D.R. and Howley, E.T. (2000) Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine and Science in Sports and Exercise* **32**, 70-84.
- Beaver, W.L., Wasserman, K. and Whipp, B.J. (1986) A new method for detecting the anaerobic threshold by gas exchange. *Journal of Applied Physiology* **60**, 2020-2027.
- Bland, J.M. and Altman, D.G. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* **1**, 307-310.
- Bosco, C., Luhtanen, P. and Komi, P.V. (1983) A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology* **50**, 273-282.

- Bouchard, C., Dionne, F.T., Simoneau, J.A. and Boulay, M.R. (1992) Genetics of aerobic and anaerobic performance. *Exercise Sports Science Reviews* **20**, 27-35.
- Brewer, J. and Davis, J.A. (1992) A physiological comparison of English professional and semi-professional soccer players. *Journal of Sports Sciences* **10**, 146-7.
- British Association of Sport and Exercise Sciences. (1997) *Guidelines for the physiological testing of athletes*. Eds: Bird, S. and Davidson, R. British Association of Sports Sciences. Physiology Section.
- Casajús, J.A. (2001) Seasonal variation in fitness variables in professional soccer players. *Journal of Sports Medicine and Physical Fitness* **41**, 463-467.
- Denis, C., Fouquet, R., Poty, P., Geysant, A. and Lacour, J.R. (1982) Effect of 40 weeks of endurance training on the anaerobic threshold. *International Journal of Sports Medicine* **3**, 208-214.
- Edwards, A.M., Mann, M., Marfell-Jones, M.J., Noakes, T.D., Rankin, D.M. and Shillington, D. (2007) The influence of moderate dehydration on soccer performance: physiological responses to 45-min out-of-doors match-play and subsequent sport-specific tests. *British Journal of Sports Medicine* **41**, 385-391.
- Edwards, A.M. and Clark, N.A. (2006) Thermoregulatory observations in soccer match-play: professional and recreational level applications using an intestinal pill system to measure core temperature. *British Journal of Sports Medicine* **40**, 133-138.
- Edwards, A.M. and Cooke, C.B. (2004) Oxygen uptake kinetics and maximal aerobic power are unaffected by inspiratory muscle training in healthy subjects where time to exhaustion is extended. *European Journal of Applied Physiology* **93**, 139-144.
- Edwards, A.M., Clark, N.A. and Macfadyen, A.M. (2003a) Lactate and ventilatory thresholds reflect the training status of professional soccer players where maximal aerobic power is unchanged. *Journal of Sports Science and Medicine* **1**, 23-29.
- Edwards, A.M., Clark, N.A. and Macfadyen, A.M. (2003b) Test performance indicators from a single soccer specific fitness test differentiate between highly trained and recreationally active soccer players. *Journal of Sports Medicine and Physical Fitness* **43**, 14-20.
- Forthomme, B., Croisier, J.L., Ciccarone, G., Crielaard, J.M. and Cloes, M. (2005) Factors correlated with volleyball spike velocity. *American Journal of Sports Medicine* **33**, 1513-1519.
- Gladden, L.B., Yates, J.W., Stremel, R.W. and Stamford, B.A. (1985) Gas exchange and lactate anaerobic thresholds: inter- and intra-evaluator agreement. *Journal of Applied Physiology* **58**, 2082-89.
- Helgerud, J., Engen, L.C., Wisloff, U. and Hoff, J. (2001) Aerobic endurance training improves soccer performance. *Medicine and Science in Sports and Exercise* **33**, 1925-1931.
- Henritze, J., Weltman, A., Schurrer, R.L. and Barlow, K. (1985) Effects of training at and above the lactate threshold on the lactate threshold and maximal oxygen uptake. *European Journal of Applied Physiology* **54**, 84-88.
- Hoffman, J.R., and Kang, J. (2002) Evaluation of a new anaerobic power testing system. *Journal of Strength and Conditioning Research* **16**, 142-148.
- Koutedakis, Y. (1995) Season variation in fitness parameters in competitive athletes. *Sports Medicine* **19**, 373-392.
- Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Pedersen, P.K. and Bangsbo, J. (2003) The Yo-Yo Intermittent Recovery Test: physiological response, reliability, and validity. *Medicine and Science in Sports and Exercise* **35**, 697-705.
- McMillan, K., Helgerud, J., Grant, S.J., Newell, J., Wilson, J., Macdonald, R. and Hoff, J. (2005) Lactate threshold responses to a season of professional British youth soccer. *British Journal of Sports Medicine* **39**, 432-6.
- Morton, R.H. (2005) On repeated measures designs: hierarchical structures and time trends. *Journal of Sports Sciences* **23**, 549-57.
- Myers, J. and Ashley, E. (1997) Dangerous curves: a perspective on exercise, lactate, and the anaerobic threshold. *Chest* **111**, 787-795.
- Noakes, T.D. (1998) Maximal oxygen uptake: "classical" versus "contemporary" viewpoints: a rebuttal. *Medicine and Science in Sports and Exercise* **30**, 1381-1398.
- Ostojic, S. M. (2003) Seasonal alterations in body composition and sprint performance of elite soccer player. *Journal of Exercise Physiology* **6**, 11-14.
- Reilly, T. (2005) An ergonomics model of the soccer training process. *Journal of Sports Sciences* **23**, 561-572.
- Reilly, T., Bangsbo, J. and Franks, A. (2000) Anthropometric and physiological predispositions for elite soccer. *Journal of Sports Sciences* **18**, 669-683.
- Reilly, T. (1996) Fitness assessment. In: *Science and soccer*. Ed: Reilly, T. London: E. & F. Spon. 25-50.
- Reilly, T., Secher, N., Snell, P. and Williams, C. (1990) Physiology of sports. London: E & FN Spon.
- Reilly, T. and Thomas, V. (1976) A motion analysis of workrate in different positional roles in professional football match-play. *Journal of Human Movement Studies* **2**, 87-97.
- Reilly, T. and Thomas, V. (1980) The stability of fitness factors over a season of professional soccer as indicated by serial factor analysis. In: *Kinanthropometry II*. Eds: Ostyn, M., Beunen, G. and Simons, J. Baltimore, MD: University Park Press. 247-257.
- Rico-Sanz, J. (1998) Body composition and nutritional assessment in soccer. *International Journal of Sport Nutrition* **8**, 113-123.
- Rienzi, E., Drust, B., Reilly, T., Carter, J. and Martin, A. (2000) Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *Journal of Sports Medicine and Physical Fitness* **40**, 162-169.
- Schmidbleicher, D., Gollhofer, A. and Frick, U. (1988) Effects of a stretch-shortening typed training on the performance capability an innervation characteristics of leg extensor muscles. In: *Biomechanics XI-A*. Eds: de Groot, G., Hollander, A., Huijijng, P. and Van Ingen Schenau, G. Amsterdam: Free University Press. 185-189.
- Stølen, T., Chamari, K., Castagna, C. and Wisloff, U. (2005) Physiology of soccer: an update. *Sports Medicine* **35**, 501-536.
- White, J.E., Emery, T.M., Kane, J.E., Groves, R. and Risman, A.B. (1988) Pre-season fitness profiles of professional soccer players. In: *Science and Football*. Eds: Reilly, T., Lees, A., Davids, K. and Murphy, W.J. London E. & F.N. Spon. 164-171.
- Yeh, M.P., Gardner, R.M., Adams, T.D., Yanowitz, F.G. and Crapo, R.O. (1983) 'Anaerobic threshold:' problems of determination and validation. *Journal of Applied Physiology* **55**, 1178-86.

Key points

- Maximal aerobic power remains fairly stable across inter- and intra-season measurements.
- Anaerobic threshold appears more sensitive of training state confirming our earlier observations.
- The professional players tended to attain optimal performances at the mid-season interval over the 3 seasons, presumably prior to the development of accumulative fatigue.

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