Sport-specific fitness testing differentiates professional from amateur soccer players where VO2max and VO2 kinetics do not

Article *in* The Journal of sports medicine and physical fitness · June 2012

5 authors, including:

Carl Wells
Perform, The National Football Centre, St. George's Park

Andrew M Edwards
Canterbury Christ Church University

Edward Winter
Sheffield Hallam University

Barry Drust
University of Birmingham

J SPORTS MED PHYS FITNESS 2012;52:245-54

Sport-specific fitness testing differentiates professional from amateur soccer players where VO_{2max} and VO_2 kinetics do not

C. M. WELLS [1], A. M. EDWARDS [2], E. M. WINTER [1], M. L. FYSH [1], B. DRUST [3]

[1]Sheffield Hallam University, Centre for Sport and Exercise Science, Sheffield, UK
[2]James Cook University, Institute of Sport and Exercise Science, Cairns, Australia
[3]Liverpool John Moores University, School of Sport and Exercise Sciences, Liverpool, UK

Aim. **The purpose of this study was to identify if sport-specific and cardiopulmonary exercise testing differentiated professional from amateur soccer players.**

Methods. **Thirty six men comprising 18 professional (mean±s: age 23.2±2.4 years) and 18 amateur (mean±SD: age 21.1±1.6 years) soccer players participated and performed four tests on separate occasions: 1) a graded exercise test to determine VO_{2max}; 2) four exercise transients from walking to $80\%\Delta$ for the determination of VO_2 kinetics; 3) the Yo-Yo Intermittent Recovery Test level 2 (Yo-Yo IR2) and 4) a repeated sprint test (RST).**

Results. **The players did not differ in VO_{2max} (professional 56.5±2.9 $mL.kg^{-1}.min^{-1}$; amateur 55.7±3.5 $mL.kg^{-1}.min^{-1}$: $P=0.484$) or VO_2 kinetic fundamental measures (τ_1 onset, professional 24.5±3.2 s; amateur 24.0±1.8 s: τ_1 cessation, professional 28.7±2.8 s; amateur 29.3±3.5 s: $P=0.923$). However, the amateurs were outperformed in the Yo-Yo IR2 (Professional 966±153 m; Amateur 840±156 m) ($P=0.034$) and RST (best time, professional 6.46±0.27 s; amateur 6.84±0.24 s, $P=0.012$).**

Conclusion. **Performance indices derived from field-based sport-specific performance tests identified significant differences between professional and amateur players ($P<0.05$). However, neither tests of VO_2 kinetics nor VO_{2max} differentiated between groups, suggesting laboratory tests of cardiorespiratory parameters are probably less consequential to soccer than sport-specific field-based observations.**

KEY WORDS: Oxygen consumption - Exercise - Soccer.

Physiological factors which limit performance during repeated-sprint sports such as soccer remain largely conjectural due to the diverse physical demands of competition.[1, 2] This inevitably complicates the identification of characteristics meaningful to performance. However, cardiopulmonary fitness is also often cited as an influential characteristic of success in soccer due to the large distances and continual dynamic movement patterns players are required to perform during a game.[3, 4] Nevertheless, the maximal aerobic capabilities of soccer players do not approach those of competitively active endurance athletes nor does maximal aerobic power (VO_{2max}) appear to differentiate between players' training state.[5] Several researchers have proposed that a VO_{2max} of ~60 $mL·kg^{-1}·min^{-1}$ is a minimal requirement for elite professional male soccer performance,[4, 6] but beyond the identification of this maximal 'threshold' it is unclear whether a laboratory test of VO_{2max} is meaningful.[7] It is conceivable that rather than a test of maximal aerobic capabilities, the ability to respond to a dynamic exercise challenge may be of greater consequence to performance in repeated-sprint sports where the movement characteristics are dynamically varied and regularly punctuated by changes in pace.[8, 9] These characteristics can potentially be tested by examining outcomes from either oxygen uptake (VO_2) dynamics or purposely designed sport-specific field tests.

VO_2 kinetics describe the rate with which VO_2 adjusts to a dynamic exercise challenge and close-

---

Corresponding author: A. M. Edwards PhD, Institute of Sport and Exercise Science, James Cook University, Cairns, QLD, 4879, Australia. E-mail: Andrew.edwards@jcu.edu.au

ly reflect changes in muscle oxygen uptake in response to alterations in exercise intensity.[10, 11] Previous studies have demonstrated VO_2 kinetics both in the moderate-[12] and heavy-intensity domains [13] are improved after short periods of endurance training, often in the absence of gains in maximal oxygen uptake (VO_{2max}). Despite this, oxygen uptake (VO_2) kinetics have rarely been compared between athletes competing at different performance levels within sports [8, 9, 14] or after contrasting training regimes.[15, 16] This is surprising since fast pulmonary VO_2 kinetics could be advantageous for intermittent sports such as soccer, where the ability to take in, deliver, use oxygen effectively and rapidly recover from repeated bouts of high-intensity exercise could influence performance.[7]

Fast VO_2 kinetics at the onset of high-intensity running reduces the oxygen deficit [13] and hence limits metabolic acidosis. Similarly, fast VO_2 kinetics during rest periods from exercise reflect enhanced recovery capabilities within muscle.[17-19] The net effect of fast VO_2kinetics during both on- and off-exercise transients would be less disruption to muscle homeostasis, which could potentially benefit performance during subsequent runs.

One investigation has recently suggested professional soccer players may have faster on-transient VO_2 kinetics than amateur players.[8] However, although the moderate intensity protocol (60% maximal power) utilised in that study presents useful new data, higher intensity observations (~70-80%) have not yet been reported, which is surprising these observations would be closer to match intensity (~75% of maximum).[4] In addition, no reports have yet examined off-transient VO_2 kinetics responses for comparison of recovery processes. Both high intensity on- and-off-transient VO_2 kinetics may be of practical importance for players in situations where they are required to race to the ball and pace a variety of high intensity activities over the duration of a game.[2, 20]

High intensity VO_2 kinetics consist of a 'fundamental' exponential phase ($\varphi 2$) and a subsequent, slower developing supplemental rise in VO_2 termed the slow component.[21] Recent studies have suggested that the slow component originates from exercising muscle,[19, 22] but controlling mechanisms remain largely conjectural. Previous research has demonstrated a slow component response during both the on- and off-transients of intermittent high-intensity exercise.[23] As the slow component has been associated with fatigue processes [24] and shown to be sensitive to differences in training status,[25] it would be valuable to determine VO_2 responses at high intensities similar to those performed during high intensity periods of competitive soccer match-play.[22]

Numerous field-based fitness tests have been developed to examine physiological characteristics of soccer players. For example, repeated sprint tests and the Yo-Yo Intermittent Recovery Test [26] have both been used for this purpose, demonstrating performance outcome differences in players performing at different levels.[9] Both tests have been included in this study to identify whether or not sport-specific or laboratory tests of cardiorespiratory fitness differentiate between professional and amateur players.

The purpose of this study is therefore to identify if measures derived from both field-based sport-specific tests and laboratory-based cardiorespiratory fitness variables differentiate professional from amateur soccer players.

Materials and methods

With institutional ethics approval, thirty six men comprising 18 professional (mean±SD): age 23.2±2.4 years, stature 1.80±0.06 m, body mass 76.4±7.5 kg and 18 amateur (mean± SD): age 21.1±1.6 years, stature 1.80±0.08 m, body mass 75.8±11.4 kg soccer players participated. All professionals had been on a full-time contract at an English professional club for at least two years. During the stage of the season that this study was conducted, a typical week for the professionals comprised five training sessions and one competitive match. Each amateur played in a local amateur league and did not train or play more than three times per week. Prior to the administration of any test, participants were screened for existing medical conditions and asked to refrain from intense physical activity or consumption of caffeine and alcohol during the preceding 12 hours.

All players performed four exercise tests, each separated by four days. An incremental step test protocol for the determination of VO_2 max was completed as the first procedure on a motorised treadmill (Saturn, HP Cosmos, Nussdorf - Traunstein, Germany). The test began at 8 $km \cdot h^{-1}$ and increased by

1 km·h^{-1} each min until volitional exhaustion. This allowed the VO_{2max} to be established and anaerobic threshold (θ_L) to be determined using standard, non-invasive gas exchange criteria.[27] If θ_L was difficult to discern using the above criteria, additional analysis of the gas-exchange data was performed using ventilatory equivalents.[28] On a subsequent occasion, participants exercised four times using a square-wave treadmill protocol for the assessment of VO_2 kinetics. Each exercise bout was separated by 30-min of passive recovery and the exercise intensities corresponded to a comfortable walk (4 km·h^{-1}) for 2-min, followed by a square-wave bout of 6-min running at 80%Δ (*very heavy* exercise domain) where delta was defined as the difference between θ_L and VO_2 max. Each square-wave transient was followed by 12-min walking at 4 km·h^{-1}. The running speed typically required to elicit 80%Δ falls within the high-intensity exercise spectrum identified during competitive match-play [2], and therefore allows VO_2 responses to be assessed at running speeds that reflect those in competitive soccer.

Two field-based tests established sport-specific fitness. First, a repeated-sprint test (RST) [29, 30] that comprised seven sprints of 30-m dissected by a 5-m deviation to the left. Each sprint was separated by a 25-s recovery jog back to the start position. Photoelectric timing gates (Brower Timing Systems, Salt Lake City, UT, USA) recorded the time taken to perform each sprint, while a hand-held stop watch was used to time the subsequent jog (W-42H, Casio, China). Test performance characteristics were recorded as 'best' and 'mean' sprint times (s), and also a 'Fatigue Index' representing the difference between best and worst sprint times. Previous research [30] has established that the exercise-to-rest ratio in the RST reflects the most demanding exercise periods of competitive match play.

The second sport-specific test performed was the Yo-Yo IR2.[26] This test comprised running 40-m shuttles (2x20-m) each separated by a 10-s jog. Running speed during the test was incremental and dictated by audio signals from a cassette tape. Maximal performance was adjudged to coincide with the inability to maintain the dictated running speed and recorded a total distance covered (m) at the point of test completion. Performance in the YIRT has been shown to be positively associated with the amount of high-intensity running performed during competitive soccer [31] and distinguishes between players of differing standard.[2, 32]

Pulmonary gas exchange was measured breath-by-breath using a respiratory mass spectrometer (MGA 1100, Marquette Electronics Inc, Milwaukee, WI, USA) and a volume turbine transducer (VMM-110, Alpha Technologies, Laguna Niguel, CA, USA). A two-point calibration was performed using two high-tolerance (±0.03%) gas mixtures (Medgraphics Corporation, St Paul, MN, USA) chosen to span the range of inspired and expired gas concentrations (Reference gas 21% O_2, 0% CO_2, Bal N_2 and Calibration gas 12% O_2, 5% CO_2, Bal N_2). A successful calibration resulted in measurement of the reference gas to within±0.03%. Accuracy of the mass spectrometer was verified immediately after each exercise test using the same precision gases. A three-litre syringe was used to calibrate the volume turbine using flow rates similar to participants' ventilation. The required tolerance for calibration was ±1%. Gas volumes were corrected to standard temperature pressure dry (STPD). An algorithm [27] was used to calculate gas exchange at the alveolar level with corrections for changes in lung volume and lung gas composition. To reduce the influence of non-physiological noise, a computer software filter (First Breath Software version 2.0, First Breath Inc, St Agatha, Ontario, Canada, 1992) was used to eliminate VO_2 data points that were greater than three standard deviations of the mean breath-to-breath difference. The breath-by-breath data were interpolated to give second-by-second values and were time-aligned to the start of exercise. Mean values for the four repeated bouts of exercise were taken to enhance the underlying response characteristics.

To characterise the kinetics of the VO_2 response, a double-exponential model [33] was applied to the data using a non-linear least-squares fitting procedure for on- and off-transients.

On-transient:

$\Delta VO_2\ (t) = A_1(1\text{-}e^{-(t-\delta 1)/\tau 1}) + A_2\,(1\text{-}e^{-(t-\delta 2/\tau 2)})$

The amplitude of the slow component for the on-transient (A_2) was characterised to the VO_2 finally achieved and that of the fundamental component (A_1) to its asymptotic value.

Off –transient:

$\Delta VO_2\ (t) = (A_1\, e^{-(t-\delta 1)/\tau 1}) + (A_2 e^{-(t-\delta 1/\tau 2)}$

In the case of the off-transient, the fundamental and slow components were constrained to begin at exercise cessation.[34]

As the initial, 'cardiodynamic' phase ($\varphi 1$) of the VO$_2$ response does not directly represent active muscle O$_2$ use, the first 20-s of the on-transient were omitted from the fitting field. Although the duration of $\varphi 1$ is likely to be less in recovery, the first 20-s of the off-transient were thought to be more than sufficient to obviate any distorting influence on the subsequent kinetics.

Accurate estimation of the oxygen deficit requires determination of baseline VO$_2$ and of the VO$_2$ demand for the exercise, with the end steady-state in VO$_2$ being assumed to be the constant O$_2$ demand throughout the exercise. However, it has been suggested that this approach is not valid for sustained supra-θ_L exercise, as the delayed development of the slow component during heavy-intensity exercise indicates that the energy demand does not remain constant.[21] The additional VO$_2$ associated with the development of the slow component during very-heavy-intensity exercise has actually been demonstrated to exceed the oxygen deficit calculated from the sub-θ_L VO$_2$ exercise intensity relationship.[35] Therefore, the oxygen deficit values for $\varphi 2$ and slow component responses in this study were calculated separately [13] and then combined to provide a measure of the total oxygen deficit incurred during the 80%Δ run.

$\varphi 2$ Oxygen deficit $= (A_1 \times TD_1) + (A_1 \times \tau_1)$

Slow component DO$_2$ $= (A_2 \times TD_2) + (A_2 \times \tau_2)$

Total oxygen deficit $= ((A_1 \times TD_1) + (A_1 \times \tau_1)) + ((A_2 \times TD_2) + (A_2 \times \tau_2))$

Statistical analysis

The statistical software package SPSS for Windows (version 11.0; SPSS Inc, Chicago, IL., USA) was used for all statistical analysis. After verification of underlying assumptions, a two-way, mixed-design analysis of variance (ANOVA) and independent sample t-tests compared groups as appropriate. Cohen's *d* effect sizes have been included in all tabular results for inter-test magnitude (large, medium and small) comparisons between professional and amateur groups. The relationships between data sets were examined using Pearson's Product Moment Correlation while the distribution of points around the regression line was measured by calculating the standard error of the estimate (SEE). Probability values equal to or less than 0.05 were considered statistically significant.

Results

VO$_2$ test performance

Independent sample t-tests revealed that there were no differences in cardiovascular fitness or performance measures derived from the VO$_{2max}$ test between the professional and amateur players (Table I).

VO$_2$ kinetic measures for professional and amateur players

The fundamental φ2 time constant for the VO$_2$ on- (τ_{1on}) and off-transients (τ_{1off}) did not differ between groups (P=0.923) (Table II). The time constant of the slow component at exercise onset (τ_{2on}) was longer in Amateurs than Professionals (P=0.034), despite similar amplitudes (Table II). However, this was not accompanied by a difference in the slow component oxygen deficit (P=0.086) or total oxygen deficit (P=0.154) between the two groups, despite the observation of a large effect size difference (d=1.15) between groups (Table II). There was no difference in the amplitude of the fundamental response (A$_1$) between professionals and amateurs at either on- (P=0.142) or off-transient, (P=0.121). Similarly, the total "gain" (G$_{TOT}$) of the on-transient response (i.e (A$_{1on}$ + A$_{2on}$)/ΔWR) did not differ between groups (Professional: 256±41 ml·min^{-1}·km^{-1}·h^{-1}; Amateur:

TABLE I.—*Physiological and performance measures (mean±SD) from the incremental test to exhaustion for the professional (N.=18) and amateur (N.=18) players.*

Measure	Professional	Amateur	Effect size *(d)*
VO$_{2max}$ (mL·kg^{-1}·min^{-1})	56.5±2.9	55.7±3.5	0.25
Time to exhaustion (s)	633±55	625±69	0.13
Speed at VO$_{2max}$ (km•h^{-1})	18.5±0.9	18.6±1.1	0.10
VO$_2$ at q_L (ml·kg^{-1}·min^{-1})	39.5±2.4	38.1±3.3	0.49

TABLE II.—*On- and off-transient VO_2 kinetics (mean±s) of professional (N.=18) and amateur (N.=18) players.*

Measure	Professional	Amateur	Effect size (*d*)
τ_1 On (s)	24.5±3.2	24.7±1.8	0.08
τ_1 Off (s)	28.7 ±2.8	29.3±3.5	0.19
TD_1 On (s)	6.7 ±2.7	8.55±2.6	0.70
TD_1 Off (s)	16.3 ±2.9	15.3±2.8	0.35
τ_2 On (s)	98.2 ±56.6*	142.4±58.6	0.77
τ_2 Off (s)	261.7 ±50.2	277.3±41.8	0.34
TD_2 On (s)	116.7 ±9.5	120.4±9.4	0.39
DO_2 Phase II (mL)	1406±42	1438±96	0.43
DO_2 slow component (mL)	1173±71	1245±52	1.16
DO_2 total (mL)	2579±85	2683±96	1.15

*significant difference between groups (P<0.05)

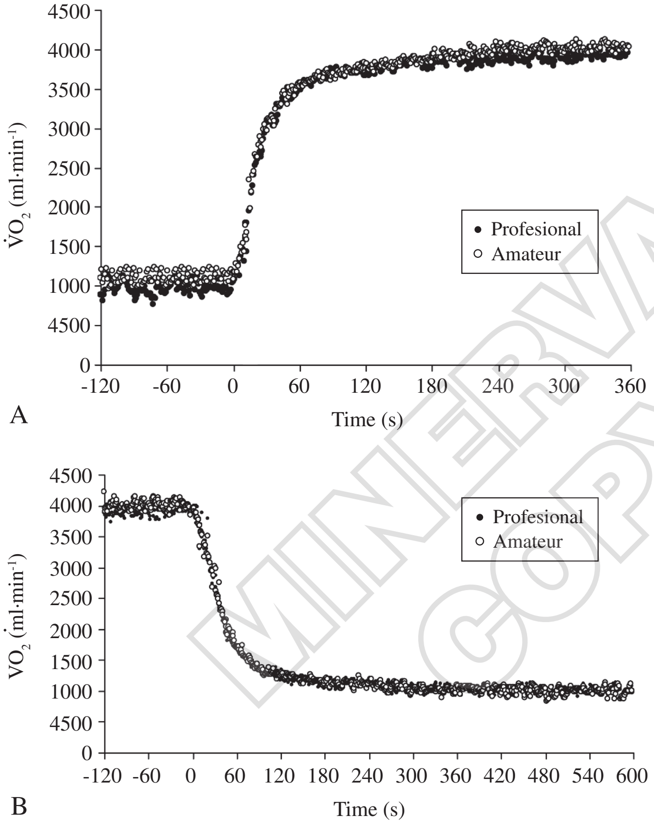

Figure 1.—A representation the 80%Δ square-wave exercise transition that was performed four times, each transition was separated by 30 min of passive recovery. The walking pace was standardised at 4 $km\cdot h^{-1}$, while the running transition varied among participants according to the criterion of individual 80%Δ. A, B) The VO_2 responses from representative professional and amateur players during the on- (A) and off-transients (B) from very heavy intensity treadmill running.

262±38 $ml\cdot min^{-1}\cdot km^{-1}\cdot h^{-1}$) (P=0.677). Examples of typical temporal profiles of the VO_2 responses during the on- and off-transients of exercise for professionals and amateurs are presented in Figure 1A, B.

Tests of soccer-specific fitness

The professionals covered a greater total distance in the Yo-Yo IR2 than the amateurs (Table III) (P=0.034). In the RST, the professionals had faster "best" sprint times (P=0.012), "mean" sprint times (P=0.014) and less fatigue than the amateurs (P=0.021). Each sport-specific test measurement demonstrated an effect size difference of greater than 0.8 (large) between Professional and Amateur players (Table III).

Relationships between physiological and performance measures

Maximal oxygen uptake was inversely related to τ_1 both for on- (r=-0.61, N.=18; P=0.001) and off-transients (r=-0.46, N.=18; P=0.046) for the professionals, but only with τ_{1on} for the amateur players (r=-0.66, N.=18; P=0.014) (Figure 2A, B). Both for professionals and amateurs, there was no evidence of a relationship between VO_{2max} and measures that represent the 'slow component' (τ_2 and A_2) for either transient.

The total distance covered in the Yo-Yo IR2 was positively correlated with VO_2 max for each group (professional: r=0.69, N.=18; P=0.014 and amateur: r=0.73, N.=18; P=0.026)

TABLE III.—*Performance (mean±s) in the Yo-Yo IR2 and RST of the professional (N.=18) and amateur (N.=18) players.*

Measure	Professional	Amateur	Effect size (*d*)
Yo-Yo IR2 (m)	966±153*	840±156	0.82
RST 'best' sprint (s)	6.46±0.27**	6.84±0.24	1.49
RST 'average' sprint (s)	6.69±0.36**	7.02±0.25	1.06
RST Fatigue Index (s)	0.36±0.15*	0.51±0.20	0.85

*significant difference between groups (P<0.05); **significant difference between groups (P<0.01).

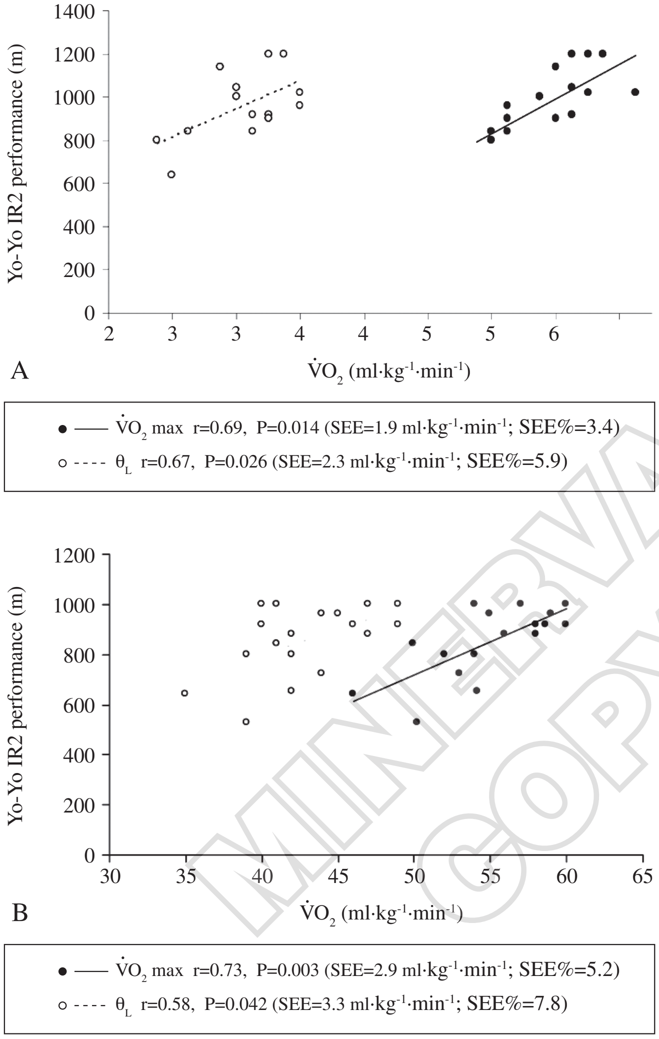

Figure 2.—A, B) The relationship between Yo-Yo IR2 performance and $\dot{V}O_2$ max and θ_L for professional (A) and amateur (B) soccer players.

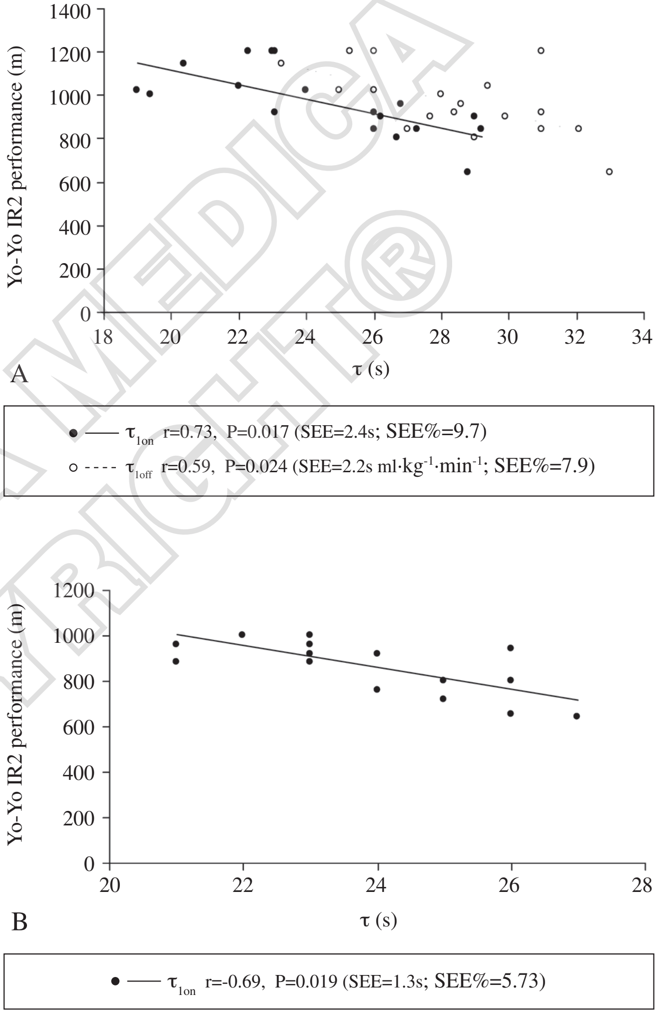

Figure 3.—A, B) The relationship between Yo-Yo IR2 performance and τ for professional (A) and amateur (B) players. For the amateur players, τ is only correlated to Yo-Yo IR2 performance at the onset of exercise.

There were negative correlations between the distance covered during the Yo-Yo IR2 and τ_1 of the on-transient when expressed within each group (Professional: r=-0.73, N.=18; P=0.017 and Amateur: r=-0.69, N.=18; P=0.019) (Figure 3A, B). The mean τ_1 of the off-transient was correlated with Yo-

Yo IR2 performance only in the professional group ($r=-0.59$, $N.=18$; $P=0.024$). There were no relationships between repeated sprint test measures and any measurements from the three other tests.

Discussion

The main observation from this study was that test indices of field-based sport-specific fitness testing differentiated between professional and amateur soccer players ($P<0.05$) while neither laboratory test of cardiorespiratory fitness (maximal or dynamic) separated the two groups.

Earlier studies have demonstrated performance gains in soccer players following aerobic training [6] and it is well known that match intensity increases with the standard of play.[29] Therefore, a greater maximal aerobic capability (VO_{2max}) might have been anticipated for the professional players. However, the VO_{2max} values reported in this study were within the lower range (56 to 62 $mL \cdot kg^{-1} \cdot min^{-1}$) previously reported for professionals[36] and it has previously been noted that VO_{2max} is not particularly sensitive to change in cardiopulmonary fitness.[5] Our results appear to support the contention that although maximal aerobic capability is important,[3, 6] among homogenous groups of players, it might not be critical to success in soccer.

The τ_{1on} values for in the current study (professional =24.5±3.2 s; amateur =24.7±1.8 s) also did not differ ($P=0.923$) and are similar to those previously reported for amateur soccer players (23.1±5.7s),[7] while being equivalent or slower than those recorded for recreationally active and endurance trained individuals (21.5±8.5 s;[37] 21.2±8.2 s;[38] 19.1±1.4 s).[39] Our results for professional and amateur players results are substantially faster than those reported recently in response to moderate intensity exercise for both professional (27.2±3.5 s) and amateur (32.3±6 s) Italian soccer players.[8] Differences in methodologies across exercise intensity-domains complicate further comparisons between studies, however, further confirmatory investigations utilising both high and low intensity protocols may indicate whether or not moderate intensity observations are meaningful to soccer performance.

The only difference in aerobic measures in this study between the professional and amateur players was the time constant of the slow component response (τ_{2on}), which was longer in the amateurs ($P=0.034$; $d=0.77$) despite the similarity in amplitude of the slow component between the two groups. However, the physiological meaning of this result is unclear as the faster τ_{2on} of the professionals is not supported by differences in the phase III oxygen deficit (DO_2) between the two groups (professional 1173±71 mL; amateur 1245±62 mL) ($P=0.086$). Mean DO_2 was only 6% larger for the amateur players, which supports the view that, although aerobic factors are clearly of some importance, they are probably not defining physiological characteristics of successful soccer players. This also suggests that the differences in the sport-specific tests between groups are unlikely to be attributable to the rate at which the slow component develops. Furthermore, previous observations have demonstrated that it is the amplitude of the slow component that is critical for performance,[25] with a decreased amplitude after training being proposed as an indicator of enhanced tolerance for high-intensity exercise.

It is also conceivable that the difference in τ_{2on} observed between the professionals and amateurs could be attributed to the complexities of fitting an exponential model to such a small, delayed and slowly emerging amplitude. For example, the exponentiality of the slow component response cannot be assumed when τ_2 is extremely slow; it is plausible that a linear model would sufficiently characterise such a response.[32] Furthermore, a two-component model as used in this study that contains several free parameters will lower confidence in parameter estimation by 1) reducing the degrees of freedom; and 2) creating a shared dependency across the parameters.[39]

The small signal-to-noise ratio inherent in slow component measurements will also contribute to low confidence in parameter estimation. Unpublished research from our laboratory revealed during an 80%Δ run by recreationally active males who possessed similar aerobic fitness to the soccer players in this study, signal-to-noise ratios of 39% for τ_{2on} and 38% for τ_{2off}. Based on these data, the±95% confidence intervals [40] for τ_2 measurements were estimated to be±33.0 s for the on- and±120 s for the off-transients. In comparison, the signal-to-noise ratio for the $\varphi 2$ phase of 80%Δ running among the recreational athletes studied was 7.2% for the on-transient and 5.4% for the off-transient. Such enhanced signal-to-noise ratios produced smaller 95% confidence interval estimates for τ_1 of±1.21 s for the on- and±1.48 s for the off-transient. Although the most appropriate method to characterise the slow component remains unclear, a two-component model separates the fundamental- and slow-component responses and offers an indication of the dynamic qualities of these components.

In contrast to the relative similarity of VO_{2max} and VO_2 kinetics between professionals and amateurs, sport-specific test performances of the two groups significantly differed. This outcome can easily be discerned via examination of effect sizes (Table III) as, for all sport-specific variables, the outcomes were above the threshold for large effects (Cohen's *d* effect size >0.8) (Table III).

The professionals outperformed the amateurs both on the Yo-Yo IR2 and RST which is consistent with recent observations,[9] suggesting applied 'fitness' related to the performance demands of the sport. The mean total distance covered in the Yo-Yo IR2 both by professionals (966±153 m) and amateurs (840±156 m) compared reasonably well with the range specified in an earlier study of elite male players (600-1320 m).[26] The sensitivity of the Yo-Yo IR2 to differentiate between performers of different standard has been reported previously,[2, 31] which indicates that the test is sensitive to differences in sport-specific fitness. In the RST, professionals were faster over a single sprint (best time: professional 6.46±0.27 s; amateur 6.84±0.24 s: P=0.012), maintained a faster speed over the seven sprints (mean time: Professional 6.69±0.36 s; amateur 6.84±0.24 s: P=0.014) and hence demonstrated less fatigue (fatigue index: professional 0.36±0.15 s; amateur 0.51±0.2 s: P=0.021). The RST performance by both groups was comparable or superior to that previously reported by [29] for elite Danish players (best time 6.80 s; mean time 7.10 s; fatigue index 0.64 s), indicating the amateurs were well-trained for repeated sprints.

The duration of the Yo-Yo IR2 suggests an aerobic element is involved in the test performance so it is unsurprising to see an association both with VO_2 max (Professional: r=0.69, N.=18; P=0.014 and Amateur: r=0.73, N.=18; P=0.026) and $\tau_{1,on}$ (Professional: r=-0.73, N.=18; P=0.017 and Amateur: r=-0.69, N.=18; P=0.019). This observation supports earlier studies that demonstrated the relevance of cardiopulmonary fitness in the performance of prolonged, high-intensity intermittent exercise.[29, 41] However, the lack of association between τ_{1on} and RST performance is in contrast to the positive correlation reported by Dupont[7] for amateur soccer players between τ_{1on} and performance of fifteen repeated 40-m sprints when expressed as relative decrease in speed during the sprints (r=0.80) and accumulated time for the sprints (r=0.80). The authors proposed that a fast VO_2 response benefits performance by limiting the disturbance to intramuscular homeostasis due to an increased contribution from aerobic metabolism. However, this assumption that fast VO_2 kinetics are beneficial for repeated sprint performance is speculative as the authors did not determine whether the faster VO_2 kinetics led to a reduced oxygen deficit. Furthermore, τ_1 was measured at the onset of moderate-intensity running (60% of maximal aerobic speed), which might not provide an accurate representation of VO_2 responses to the onset of $>\theta_L$ exercise [25, 42] as would be performed during the repeated sprints. The similar VO_2 kinetic profiles of professionals and amateurs reported in this investigation suggests that potential benefits of possessing fast VO_2 kinetics, such as a reduced oxygen deficit or enhanced recovery capabilities, do not discriminate performance in the Yo-Yo IR2 and RST among players of differing standard.

Closer analysis of the Yo-Yo IR2 and VO_{2max} protocols demonstrates that the running speeds attained during the latter stages of the Yo-Yo IR2 approached 19 km·h^{-1}, and were thus similar, or in excess of those achieved at VO_{2max}. It is well known that the lower economy of intermittent compared with continuous running results in increased metabolic disturbances [43], and it is probable that the intensity of the Yo-Yo IR2 was such that substantial anaerobic energy transfer was required to support aerobic processes. This indicates that superior performance of the professional players in the Yo-Yo IR2 test might be attributable to an enhanced capability for the transfer of energy via anaerobic rather than aerobic pathways. The superior repeated sprint test performance of professionals, despite both groups being matched for aerobic fitness, further emphasises the importance of differences in sport-specific performance between the professionals and amateurs.[8, 9]

It appears that the decisive factor in determining fitness for elite soccer performance in this study might be attributable to the specific movement and performance replicative demands of sport –specific fitness testing rather than standard laboratory tests of aerobic capabilities. This observation is consistent with recent studies in which cardiopulmonary fitness measurements have not: 1) differentiated between players of differing standard;[44] 2) been correlated to high-intensity exercise during match-play,[31] or 3) identified change in the training state of elite soccer players.[5] Such an observation might have important practical implications for the future training and testing of professional soccer players.

The findings of this study are based on a cross section of professional and amateur players who clearly did not perform the same routine training on a week-to-week basis. As cardiovascular and peripheral adaptations are influenced by the volume,[45] duration [46] and intensity [47] of training, it is not possible, in this study, to discern the precise cause for the observed differences and similarities in test performances. Therefore, a well-controlled longitudinal training study might be required to elucidate the mechanisms controlling the physiological observations of this study.

Conclusions

In conclusion, the adult male professional soccer players in this study possessed a superior capability for soccer-specific high-intensity running than their amateur counterparts, despite the high intensity VO_2 kinetics profiles and peak aerobic fitness of the two groups being largely indistinguishable. The findings of this study suggest that testing of players in response to intermittent sport-specific testing is preferential to either VO_{2max} or VO_2 kinetics.

References

1. Drust B, Atkinson G, Reilly T. Future perspectives in the evaluation of the physiological demands of soccer. Sports Med 2007;37:783-805.
2. Mohr M, Krustrup P, Bangsbo J. Match performance of high-standard soccer players with special reference to the development of fatigue. J Sports Sci 2003;21:519-28.
3. McMillan K, Helgerud J, Grant SJ, Newell J, Wilson J, MacDonald R, Hoff J. Lactate threshold responses to a season of Professional British Youth Soccer. Br J Sports Med 2005;39:432-6.
4. Reilly T, Bangsbo J, Franks A. Anthropometric and physiological predispositions for elite soccer. J Sports Sci 2000;18:669-83.
5. Edwards AM, Clark N, Macfadyen AM. Lactate and ventilatory thresholds reflect the training status of professional soccer players where maximal aerobic power is unchanged. J Sports Sci Med 2003a;1:23-9.
6. Helgerud J, Engen LC, Wisloff U, Hoff J. Aerobic endurance training improves soccer performance. Med Sci Sports Exerc 2001;33:1925-31.
7. Dupont G, Millet GP, Guinhouya C, Berthoin S. Relationship between oxygen uptake kinetics and performance in repeated running sprints. Eur J Appl Physiol 2005;95:27-34.
8. Rampinini E, Sassi A, Morelli A, Mazzoni S, Maurizio F, Coutts AJ. Repeated-sprint ability in professional and amateur soccer players. Appl Physiol Nut Met 2009;34:1048-54.
9. Rampinini E, Sassi A, Azzalin A, Castagna C, Menaspa P, Carlomagno D, Impellizzeri FM. Physiological determinants of Yo-Yo intermittent recovery tests in male soccer players. Eur J Appl Physiol 2010;108:401-9.
10. Barstow TJ and Mole PA. Simulation of pulmonary O_2 uptake during exercise transients in humans. J Appl Physiol 1987;63:2253-61.
11. Grassi B, Poole DC, Richardson RS, Knight DR, Erickson BK, Wagner PD. Muscle O_2 uptake in humans: implications for metabolic control. J Appl Physiol 1996;80:988-98.
12. Phillips SM, Green HJ, MacDonald MJ, Hughson RL. Progressive effect of endurance training on VO_2 kinetics at the onset of submaximal exercise. J Appl Physiol 1995;79:1914-20.
13. Demarle AP, Slawinski JJ, Laffite LP, Bocquet VG, Koralsztein JP, Billat VL. Decrease of O_2 deficit is a potential factor in increased time to exhaustion after specific endurance training. J Appl Physiol 2001;90:947-53.
14. Ingham SA, Carter H, Whyte GP, Doust JH. Comparison of the oxygen uptake linetics of club and olympic champion rowers. Med Sci Sports Exerc 2007;39:865-71.
15. Berry M, Moritani T. The effects of various training intensities on the kinetics of oxygen consumption. J Sports Med Phys Fitness 1985;25:77-83.
16. Berger NJ, Tolfrey K, Williams AG, Jones AM. Influence of continuous and interval training on oxygen uptake on-kinetics. Med Sci Sports Exerc 2006;38:504-12.
17. Linnarson D. Dynamics of pulmonary gas exchange and heart rate changes at the start and end of exercise. Acta Physiol Scand 1974;415:1-68.
18. Paterson DH, Whipp BJ. Asymmetries of oxygen uptake transients at the on- and offset of heavy exercise in humans. J Physiol 1991;443:575-86.
19. Rossiter HB, Ward SA, Kowalchuk JM, Howe FA, Griffiths JR, Whipp BJ. Dynamic asymmetry of phosphocreatine concentration and O_2 uptake between the on- and off-transients of moderate- and high-intensity exercise in humans. J Physiol 2002;541:991-1002.
20. Edwards AM, Noakes TD. Dehydration: cause of fatigue or sign of pacing in elite soccer? Sports Med 2009:39:1-13.
21. Whipp BJ. The slow component of O_2 uptake kinetics during heavy exercise. Med Sci Sports Exerc 1994;2:1319-26.
22. Poole DC, Barstow TJ, Gaesser GA, Willis WT, Whipp BJ. VO_2 Slow component: physiological and functional significance. Med Sci Sports Exerc 1994;26:1354-8.
23. Turner PA, Cathcart AJ, Parker ME, Butterworth C, Wilson J, Ward SA. Oxygen uptake and muscle desaturation kinetics during intermittent cycling. Med Sci Sports Exerc 2006;38:492-503.
24. Casaburi R, Storer TW, Ben Dov I, Wasserman K. Effect of endurance training on possible determinants of VO_2 during heavy exercise. J Appl Physiol 1987;62:199-207.
25. Carter H, Jones A, Barstow TJ, Burnley M, Williams CA, Doust, JH. Effects of endurance training on oxygen uptake kinetics during treadmill running. J Appl Physiol 2000;89:899-907.
26. Bangsbo, J. Yo-Yo tests, first ed, August Krough Institute, Copenhagen, Denmark. HO + Storm; Copenhagen, Denmark; 1996.
27. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol 1986;60:2020-7.
28. Whipp BJ, Davies JA, Torres F, Wasserman K. A test to determine parameters of aerobic function during exercise. J Appl Physiol 1981;50:217-21.

29. Bangsbo J. Fitness training in football – a scientific approach. Bagsvaerd: HO Storm; 1994.
30. Wragg CB, Maxwell NS, Doust JH. Evaluation of the reliability and validity of a soccer-specific field test of repeated sprint ability. Eur J Appl Physiol 2000;83:77-83.
31. Krustrup P, Mohr M, Amstrup T, Rysgaard T, Johansen J, Steenberg A *et al.* The Yo-Yo Intermittent Recovery Test: physiological response, reliability, and validity. Med Sci Sports Exerc 2003;35:697-705.
32. Bangsbo J, Iaia M, Krustrup P. The Yo-Yo Intermittent Recovery Test: a useful tool for evaluation of physical performance in intermittent sports. Sports Med 2008;38:37-51.
33. Barstow TJ, Mole, P.A. Linear and nonlinear characteristics of oxygen uptake kinetics during heavy exercise. J Appl Physiol 1991;71:2099-106.
34. Özyener F, Rossiter H, Ward SA, Whipp BJ. Influence of exercise intensity on the on- and off-transient kinetics of pulmonary oxygen uptake in humans. J Physiol 2001;533:891-902.
35. Özyener F, Rossiter HB, Ward SA, Whipp BJ. Negative accumulated oxygen deficit during heavy and very heavy intensity cycle ergometry in humans. Eur J Appl Physiol 2003;90:185-90.
36. Ekblom B. Applied physiology of soccer. Sports Med 1986;3:50-60.
37. Barstow TJ, Jones AM, Nguyen PH, Casaburi R. Influence of muscle fibre type and pedal frequency on oxygen uptake kinetics of heavy exercise. J Appl Physiol 1996;81:1642-50.
38. Koga S, Tomoyuki S, Shibasaki M, Kondo N, Fukuba Y, Barstow TJ. Kinetics of oxygen uptake during supine and upright heavy exercise. J App Physiol 1999;87:253-60.
39. Whipp BJ, Rossiter HB. The kinetics of oxygen uptake: physiological inferences from the parameters. In Oxygen Uptake Kinetics in Sport, Exercise and Medicine, eds. Jones, A.M. and Poole, London and New York: D.C.. Routledge; 2005.
40. Lamarra N, Whipp BJ, Ward SA, Wasserman K. Effects of interbreath fluctuations on characterising exercise gas exchange kinetics. J Appl Physiol 1987;62:2001-12.
41. Tomlin DL, Wenger HA. The relationship between aerobic fitness and recovery from high-intensity intermittent exercise. Sports Med 2001;31:1-11.
42. Carter H, Pringle JSM, Jones AM, Doust JH. Oxygen uptake kinetics during treadmill running across intensity domains. Eur J Appl Physiol 2002;86:347-54.
43. Christensen EH, Hedman R., Holmdahl I. The influence of rest pauses on mechanical efficiency. Acta Physiol Scand 1960;48:433-47.
44. Edwards AM, Clark N, Macfadyen AM. Test performance indicators from a single soccer specific fitness test differentiate between highly trained and recreationally active soccer players. J Sports Med Phys Fitness 2003b;43:14-20.
45. Hickson RC. Skeletal muscle cytochrome c and myoglobin, endurance and frequency of training. J Appl Physiol 1981;51:746-9.
46. Fox EL, Bartels RL, Billings CE, O'Brien R, Bason R, Mathews DK. Frequency and duration of interval training programs and changes in aerobic power. Med Sci Sports 1975;5:18-22.
47. Harms SJ, Hickson RC. Skeletal muscle mitochondria and myoblobin, endurance and intensity of training. J Appl Physiol 1983;54:798-802.

Received on February 22, 2011.
Accepted for publication on April 12, 2012.