Title: Influence of Oxygen Uptake Kinetics on Physical Performance in Youth Soccer

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Abstract

**Purpose:** To examine the relationship between oxygen uptake kinetics ($V_O^2$ kinetics) and physical measures associated with soccer match-play, within a group of highly trained youth soccer players.

**Methods:** Seventeen highly trained youth soccer players (age: $13.3 \pm 0.4$ yr, self-assessed Tanner Stage: $3 \pm 1$) volunteered for the study. Players initially completed an incremental treadmill protocol to exhaustion, to establish gaseous exchange threshold (GET) and $V_O^2_{max}$ ($59.1 \pm 5.4$ mL kg$^{-1}$ min$^{-1}$). On subsequent visits players completed a step transition protocol from rest–moderate intensity exercise, followed by an immediate transition from moderate–severe intensity exercise (moderate: $95\%$GET, severe: $60\%$Δ), during which $V_O^2$ kinetics were determined. Physical soccer-based performance was assessed using a maximal Yo-Yo Intermittent Recovery test level 1 (Yo-Yo IR1) and via GPS derived measures of physical soccer performance during soccer match-play, 3 $2 \times 20$min, 11 v 11 matches, to gain measures of physical performance during soccer match-play.

**Results:** Partial correlations revealed significant inverse relationships between the unloaded to moderate transition time constant ($\tau$) and: Yo-Yo IR1 performance ($r = -0.58, P = 0.02$) and GPS variables (Total distance (TD): $r = -0.64, P = 0.007$, High speed running (HSR): $r = -0.64, P = 0.008$, High speed running efforts (HSReff): $r = -0.66, P = 0.005$).

**Conclusion:** Measures of $V_O^2$ kinetics are related to physical measures associated with soccer match-play and could potentially be used to distinguish between those of superior physical performance, within a group of highly-trained youth soccer players.

**Key Words:** Team Sports, Intermittent Exercise, Youth Soccer, $V_O^2$ Kinetics
Introduction

The contribution of aerobic metabolism during soccer match play is dominant, accounting for up to 90% of the energy required (Iaia, Rampinini & Bangsbo, 2009). However, as a consequence of the numerous, discrete high intensity actions incurred throughout competitive match-play (Bangsbo, Mohr & Krstrup, 2006), the contribution of anaerobic energy pathways is likely to be high at certain points during the game. The ability to perform, repeat and sustain high intensity exercise is essential for elite soccer performance (Iaia et al., 2009). Consequently, faster oxygen uptake kinetics ($V_O^2$ kinetics) during transitions from low to high intensity exercise could preserve the capacity of the anaerobic energy systems and thus enhance an individual’s tolerance to fatigue (Glaister, 2005).

In addition, faster $V_O^2$ kinetics could result in a higher total energy turnover during high intensity exercise, when added to maximal anaerobic energy turnover. Therefore, resulting in the ability to maintain, repeat and sustain high intensity exercise during soccer match-play.

Global measures of aerobic capacity, like maximal oxygen consumption ($V_O^{2max}$), have been examined in relation to measures of physical soccer performance (Rebelo, Brito, Seabra, Oliveira & Krstrup, 2014). Measures of
$VO_{2\text{max}}$ however, have shown an inability to distinguish between players of the same playing level (Rampinini et al., 2010; Stroyer, Hansen & Klausen, 2004) and is less sensitive to training when compared to the Yo-Yo IR1 & IR2 tests, which are measures of intermittent running capacity (Bangsbo, Iaia & Krstrup, 2008). Measures of $VO_{2}$ kinetics, therefore have been proposed as an alternative determinant of sports performance (Burnley & Jones, 2007). For example, while Rampinini et al (2010) reported no significant differences in measures of $VO_{2\text{max}}$ between professional and amateur adult soccer players, the professional soccer players were shown to possess faster $VO_{2}$ kinetics than their amateur counter-parts, as measured by the time constant of the transition to moderate intensity exercise ($27.2 \pm 3.3$ vs. $32.3 \pm 5.7$ s). Furthermore, Rampinini et al. (2010) demonstrated that the time constant from rest to moderate intensity exercise, was ‘largely’ related to both the Yo-Yo IR1 ($r = -0.60$) and Yo-Yo IR2 ($r = -0.65$). Whether this effect has an impact on soccer match-play or is apparent within a cohort of highly trained youth soccer players is yet to be investigated.

Research within adult populations has produced equivocal findings, with some studies demonstrating significant associations between superior $VO_{2}$ kinetics and intermittent exercise capacity (Dupont et al., 2005; Rampinini et al., 2009; Rampinini et al., 2010), while others have reported no association between the two (Buchheit, Hader & Mendez-Villanueva, 2012; Christensen et al., 2011; Wells et al., 2012). Research in both male and female adolescents, however, has demonstrated faster $VO_{2}$ kinetics in soccer trained individuals in comparison to their untrained counterparts (Marwood et al., 2011; Unnithan, Roche, Garrard, Holloway & Marwood, 2015). Consequently, $VO_{2}$ kinetics may impact upon measures of physical soccer performance during elite youth soccer match-play. Previous studies, however, have limited applicability to performance during soccer match-play as they only compared untrained and trained participants $VO_{2}$ kinetics during laboratory controlled treadmill exercise and did not relate this to performance during soccer match-play. As a result, while soccer trained individuals have been shown to demonstrate superior $VO_{2}$ kinetics when compared to untrained or amateur athletes, it is unclear to what extent measures of $VO_{2}$ kinetics are related to physical measures of performance, obtained during soccer match-play, within a group of highly-trained adolescent soccer players.

Initial research examining $VO_{2}$ kinetics in soccer have assessed $VO_{2}$ kinetics using a single square-wave transition (unloaded – moderate intensity) protocol (Rampinini et al., 2010; Marwood et al., 2011; Unnithan et al., 2015). Soccer match-play, however, incorporates severe intensity exercise which is often initiated from an elevated
baseline work rate ($V_O^2$), resulting in the recruitment of higher order motor units (preferential recruitment of type II muscle fibres) (Nyberg et al., 2016). Consequently, in order to mimic these soccer-specific workload transitions, a novel methodological approach was used by Nyberg et al. (2016). These authors utilised a double-step exercise protocol, when examining the impact of additional speed endurance training on Yo-Yo IR1 performance, in highly trained adult soccer players. The examination of $V_O^2$ kinetics profiles during a step transition, work-to-work protocol (unloaded – moderate and moderate - severe) therefore allows for a more representative test in a soccer-specific cohort and provides a novel means for examining $V_O^2$ kinetics in relation to the demands that are presented during soccer match play. As a result, the purpose of this study was to examine the relationship between $V_O^2$ kinetics, during a step transition work-to-work protocol, and measures of physical performance obtained during soccer match-play, within a group of highly trained youth soccer players. It was hypothesised that those players who demonstrate faster pulmonary $V_O^2$ kinetics during both transitions (unloaded – moderate & moderate – severe) would also demonstrate superior measures of physical performance during soccer match-play.

**Methods**

**Participants**

Seventeen highly trained youth soccer players aged between 12 and 14 years volunteered to participate in this study. All participants were outfield players (5 defenders, 6 midfielders and 6 attackers) from the same Category One Premier League Football Academy. Prior to the commencement of the study, all players completed medical health questionnaires and training history questionnaires. Table 1 displays all anthropometric and screening measures. Maturation status was quantified using self-assessment, Tanner Stage method (Tanner, 1962) and maturity offset (Mirwald, Baxter-Jones, Bailey & Beunen, 2002). Players and their parents were informed about all procedures and requirements involved before providing written informed consent and assent from parents and participants, respectively. Ethical approval was granted from the local university ethics committee.

*** Insert Table 1 Here***

**Study Design**

Data collection was conducted over a three-week period at the beginning of a competitive season (pre-season) at a period where there were no competitive matches; during this period laboratory and field tests were conducted.
The players visited the laboratory on 3 separate occasions, performed a field test (Yo-Yo IR1) and were involved in three 11 v 11 matches (including the same pitch dimensions, the same composition of players in the same positions and the same coaches, excluding goalkeepers from the analysis). During the periods of laboratory testing, training only consisted of light technical practices, however, recovery periods of 24 hours were implemented between all laboratory tests. In the first laboratory visit, players performed an incremental, ramp treadmill protocol for the assessment of players’ gaseous exchange threshold (GET) and $\dot{V}O_2^{max}$. Players returned to the laboratory on two further occasions. These two, separate visits to the laboratory were identical and required the participant to complete a step transition protocol (from rest - moderate exercise, followed by an immediate transition from moderate - severe intensity exercise) on a motorised treadmill for the assessment of their pulmonary oxygen uptake kinetics. All testing was completed at the same time of day (± 2 hours), with room temperature, humidity and pressure corresponding to 20.5 ± 1.5 ºC, 61.0 ± 1.4 % and 1016 ± 3 mmHg respectively, for laboratory testing.

Once all laboratory testing had been completed and a minimum of 48 h recovery had been undertaken, players performed a maximal Yo-Yo IR1 field test. Subsequent to this and following a minimum of 48 h recovery, the players’ physical performance during soccer match play was assessed during 3 separate, 11 v 11 matches, with a minimum of 48 h recovery between each match. Matches were comprised of 2 x 20 min halves, with a 5 min rest interval in between halves. Players’ match activities were monitored and analysed using 10 Hz global positioning systems (GPS; Catapult, Melbourne, Australia).

All testing procedures (laboratory & field) were preceded by a 10 min warm-up, consisting of low intensity running, dynamic stretching and then moderate intensity running. Following all tests a 5 min cool down, consisting of low intensity running and static stretching, was conducted. All field testing and matches were conducted on third generation artificial pitch in clear and dry conditions with minimal wind. Mean temperature, humidity and pressure were 19.8 ± 2.4 ºC, 59.0 ± 3.4 % and 1009 ± 1 mmHg, respectively. Participants were instructed to refrain from exercise on the days preceding each test and to maintain a normal diet throughout testing. Players were also informed to refrain from consuming any drinks containing sugar or caffeine as well as the consumption of any food in the two hours preceding any test.
Assessment of Maximal Oxygen Uptake and Gaseous Exchange Threshold

Upon arrival at the laboratory and following pre-participation screening procedures (including completion of training and health questionnaires as well as the assessment of players’ resting heart rate and blood pressure), participants were fitted with a Polar Heart rate monitor (Polar Electro, Kempele, Finland) and face-mask (Hans Rudolph, Hans Rudolph, Kansas City, USA), which was connected to an online gas analysis system (Cortex MetaMax 3B, Cortex Biophysik GmbH, Leipzig, Germany). The online gas analyser was calibrated prior to each visit according to the manufacturer’s instructions, using a known gas concentration and a 3-L syringe for manual volume calibration of the ventilation sensors. Following a standardised 10 min warm up and a full description of the test and safety procedures, participants began to run at a speed of 8 km/h at a 1% incline (Jones & Doust, 1996) on a motorised treadmill (HP Cosmos, Pulsar, Sportgerate GmbH, Nussdorf, Germany). The speed of the treadmill was increased by 1 km/h every two minutes, this continued until participants reached 90% of their age predicted heart rate max (207 – (0.7 x age)) (Gellish et al., 2007). At this point, the treadmill speed remained constant whilst the incline of the treadmill was increased by 1% every minute until volitional exhaustion; this procedure was employed to avoid over-striding and potential early termination and inaccurate assessment of participant’s $V_{O2}$max. This method has been successfully used before to elicit $V_{O2}$max during treadmill running in young populations (Williams, Carter, Jones & Doust, 2001). $V_{O2}$max was taken as the highest 15 sec average during the test (Astorino, Robergs, Ghiasvand, Marks & Burns, 2000). Test criteria for a maximal effort, were the achievement of at least two of the following three performance values: 1) respiratory exchange ratio (RER) above 1.00, 2) plateau in $V_{O2}$ despite an increasing speed (increase in $V_{O2}$ of < 2 mL·kg⁻¹·min⁻¹) 3) heart rate ±10 beats/min of age predicted maximal heart rate (Cooke, 2009). The incremental, ramp treadmill protocol resulted in 100% percent of the participants reaching an RER value of greater than 1.00 and a heart rate value within ±10 beats/min of age predicted maximal heart rate, while 88% of the participants presented a plateau in $V_{O2}$ despite an increase in speed. It has previously been shown, however, that only a minority of children present a plateau in $V_{O2}$ during treadmill exercise (Armstrong & Welsman, 1994) and that children can exercise to exhaustion during incremental exercise without exhibiting a $V_{O2}$ plateau (Welsman & Armstrong, 1996). Therefore, as all participants achieved two of the stated criteria and the presence of a $V_{O2}$ plateau is not commonly exhibited in children, the term $V_{O2}$max was adopted throughout.
The gaseous exchange threshold (GET) was identified using the V-slope method (\(V_{CO_2}\) (ordinate), \(V_{O_2}\) (abscissa)) (Beaver, Wasserman & Whipp, 1986). Two regression lines were created based upon the relationship between \(V_{CO_2}\) and \(V_{O_2}\). The intercept point between the two regression lines was then visually identified, with the \(V_{O_2}\) value at the intercept (GET) being extrapolated to the abscissa. To identify the speed at GET, a regression equation was formulated for \(V_{O_2}\) and running velocity, for each individual. The individual’s \(V_{O_2}\) at GET was then inputted into the individual’s respective regression equation to calculate the running velocity at GET. The V-slope method has been shown to be a viable and reliable method for detecting and identifying the gaseous exchange threshold in children (Fawkner, Armstrong, Childs & Welsman, 2002; Unnithan, Timmons, Paton & Rowland, 1995). The GET was assessed by two individual researchers (experienced in the detection of GET), demonstrating 82% agreement (14 out of 17). For the remaining three participants, a third researcher, also experienced in the detection of GET, was approached to verify the GET. Following this test, the treadmill speed corresponding to 95% GET and 60% of the difference between GET and \(V_{O_2\text{max}}\) (60%\(\Delta\)) were calculated for each individual.

**Assessment of pulmonary oxygen uptake kinetics**

On the two remaining visits to the laboratory, each participant completed two transitions for each change in workload (unloaded – moderate and moderate – severe), meaning the \(V_{O_2}\) response was averaged from two transitions. Previous research has demonstrated that acceptable confidence intervals for \(\tau\) when averaging the \(V_{O_2}\) response from two transitions (Marwood et al., 2011; Unnithan et al., 2015). The work-to-work kinetics protocol consisted of 3 min unloaded (standing), 4 min running at a speed equivalent to 95% GET (moderate intensity) and a run to exhaustion at a speed equivalent to 60%\(\Delta\) (severe intensity). Prior to the test, participants were fitted with a Polar heart rate monitor and face mask, which was connected to an online expired gas analysis system. Participants were also familiarised with the transition to each speed and given sufficient time to practise until they felt comfortable with both transitions (unloaded – moderate and moderate – severe). Participants ran for no longer than 5 sec at the higher intensities during familiarisation. Following familiarisation to the speed transitions, participants rested, allowing their heart rate to return to pre-exercise values, before commencing the test. During the test, verbal encouragement was provided throughout for participants to continue for as long as possible, however no visual feedback relating to exercise duration was given to the participants during the test.
For the unloaded to moderate transition the treadmill was set at the relevant intensity (95% GET; average = 10.4 ± 1.0 km/h, range = 8.8 – 12.2 km/h) for each individual, while the participant straddled the treadmill. The participant was then given a 10 second countdown at the end of the unloaded phase, at which point they lowered themselves onto the moving treadmill and began exercising. For the transition from moderate to severe intensity the participant remained running on the treadmill. The time taken for each exercise transition was in all cases < 5 seconds, thus having minimal effects on the $\dot{V}O_2$ kinetic response as this would be contained within the cardiodynamic phase of the oxygen uptake response to an increase in intensity (Whipp & Rossiter, 2005).

**Mathematical modelling of oxygen uptake kinetics**

Prior to the modelling of the $\dot{V}O_2$ kinetics errant breaths (coughing, swallowing, sighing, etc.) were removed from the raw data set so as not to distort or skew the underlying physiological response. Errant breaths were defined as a breath that was different to the mean of the surrounding four breaths by more than four times the standard deviation of the same surrounding four data points (Jones & Poole, 2005, Marwood et al., 2011). Both data-sets from each stage (unloaded – moderate and moderate – severe) were time aligned and ensemble averaged to enhance the underlying physiological response characteristics for all intensities. Each ensemble average was then linearly interpolated second-by-second prior to the modelling process. Custom written software in Microsoft Excel, using the Solver function, was utilised for all modelling processes.

Pulmonary oxygen uptake kinetics for the unloaded - moderate and moderate - severe transitions were modelled separately, due to the difference in the characteristics of the kinetic response for each increase in intensity. For both, unloaded – moderate and moderate – to severe transitions, the goal of the modelling process was to isolate the fundamental phase (Whipp & Rossiter, 2005) of $\dot{V}O_2$ kinetic response (equation 1). To eliminate the influence of the cardiodynamic phase on the modelling of $\dot{V}O_2$ kinetics, the initial 20 seconds from the unloaded to moderate phase and initial 15 seconds of the moderate to severe phase were removed prior to the modelling process. A time delay of 20 seconds is often employed to accommodate the cardiodynamic phase (Whipp & Rossiter, 2005); however, a 15 second time delay was adopted for the moderate to severe transition due to elevated baseline blood flow incurred from the prior moderate intensity (Buchheit, Laursen & Ahmaidi, 2009). Following the cardiodynamic phase, $\dot{V}O_2$ kinetics were assumed to develop initially via a single exponential term (fundamental phase), following a delay relative to the start of exercise of the form:
\[ V_{O2(t)} = V_{O2(b)} + A_{VO2} \cdot (1 - \exp^{-\left(\frac{t-TD}{\tau}\right)}) \]  

[1]

Where \( V_{O2(b)} \) is the baseline \( V_{O2} \), which was taken as the last 30 seconds of oxygen uptake during 3 minutes unloaded phase or steady state value of moderate for mod – severe transition. \( A_{VO2} \) represents the asymptotic amplitude of the fundamental component of the response; \( \tau \) is the time constant of the fundamental component and \( TD \) is the time delay similar, but not equal to the cardiodynamic-fundamental phase transition time. For the unloaded – moderate transition, the fundamental phase was considered \textit{a priori} to encapsulate the entire 4-minute transition since exercise was undertaken below the GET. For the moderate – severe transition, the fitting strategy was designed to identify the onset of the “slow component” of the response to exercise, and thus isolate the fundamental component. Starting at 60 s, the fitting window was therefore widened by 1 s until the end of exercise with the time constant and reduced chi-square value of the curve of best fit for each time window plotted against time. The onset of the slow component could then be identified as the coincident point at which a plateau or minima in the value of \( \tau \) and a minima in chi-square, followed by a progressive increase in these values, could be determined as its value becomes affected by the slow component. The time at which this occurred was used as the optimal fitting window with which to determine the kinetics of the fundamental phase of \( V_{O2} \) kinetics. The phase III (Whipp & Rossiter, 2005) of oxygen uptake (steady state in the unloaded – moderate transition) was taken as the sum of \( V_{O2(b)} \) and \( A_{VO2} \). The amplitude of the slow component during the moderate – severe transition was calculated as \( V_{O2} \) at exhaustion minus the phase III \( V_{O2} \).

**Yo-Yo Intermittent Recovery Test Level 1**

For the Yo-Yo IR1 test, cones were placed 20 m apart, with a 5 m recovery zone marked out at one end. The Yo-Yo IR1 test requires participants to run 2 x 20 m shuttle runs at increasing speeds, interspersed with 10 seconds of active recovery. The pace of the test was controlled by audio signals emitted from a CD player (Sony CFD-V7, Sony, Tokyo, Japan). For the Yo-Yo IR1 test players were required to run until volitional termination of the test or, when they have twice failed to meet the designated cones in time with the audio signal, at which point they are removed from the test. The test score is the distance covered at the point they withdraw from the test. During the test, players were allowed to consume fluids ad libitum. Current findings support the use of the Yo-Yo IR1 test as a valid measure of physical performance in soccer, particularly within youth populations (Bangsbo et al., 2008;
Krustrup et al., 2003). All players were familiar with the Yo-Yo IR1, as it is a fitness test regular employed (4 times a season) by the respective Academy.

**Monitoring Soccer Match-Play**

For the assessment of participants’ performance during soccer match-play, three separate, 11 v 11 matches (including the same pitch dimensions, the same composition of players in the same positions and the same coaches) were conducted in the players’ regular training sessions and analysed using 10 Hz GPS and Polar heart rate monitors. As there were only 17 outfield players recruited for the present study, 3 additional outfield players and 2 goalkeepers were used to make up the numbers. These players were not involved within any other aspect of the study and at no point was any data obtained or analysed in respect to these players. Each match was conducted on the same third generation artificial pitch with the same dimensions (90 x 50 m) and at the same time of day. Matches were comprised of 2 x 20 min halves with a 5 min rest interval between halves. The composition of the teams and positions remained the same for all three matches and each participant was assigned their own GPS unit for all matches. Matches were performed on three separate occasions within the same week with a consistent recovery of 48 hrs between matches. Prior to each match, an appropriate and thorough warm-up, as well as a 20 minute technical drill was undertaken by all participants. The mean number of satellites during data collection were 8.0 ± 0.5, 8.3 ± 0.4 and 8.2 ± 0.6 for matches 1, 2 and 3 respectively. Furthermore, the mean horizontal dilution of position (HDOP), which is a reflection of the accuracy and quality of the signal (Jennings, Cormack, Coutts, Boyd & Aughey, 2010) were 1.45 ± 0.25, 1.31 ± 0.11 and 1.31 ± 0.08 for matches 1, 2 and 3 respectively.

Following each match, the GPS data was downloaded and analysed using Catapult Software (Catapult, Melbourne, Australia) and specially designed Microsoft Excel spreadsheets. Following this an average of the 3 games was calculated for each player for each variable. Data was recorded for the whole match, each 20 min half and into successive 5 min epochs (e.g. 0 – 5 min, 1 – 6 min, 2 – 7 min, 3 – 8 min, etc), to establish and quantify the peak 5 min epoch (identified as the 5 min epoch with the highest amount of high speed running distance), the subsequent 5 min epoch to the peak 5 min epoch and the mean of the cumulative 5 min epochs throughout the match. These were then averaged over the 3 matches. The peak 5 min epoch provides a surrogate measure of the highest amount of high speed distance that a player can perform within a 5 min period during soccer match-play, whereas the mean of the cumulative 5 min epochs throughout an entire match provides an indirect measure of a player’s ability to sustain their levels of physical performance during match-play. Finally, the subsequent 5 min
epoch following the peak 5 min epoch provides an estimate of a player’s ability to ‘recover’ and maintain their levels of physical performance, immediately following an exhaustive period of activity. Previous research has used discrete 5 min epochs (0-5 min, 5-10 min, etc.) to identify the peak 5 min interval during soccer match-play (Bradley et al., 2009). The adoption of such criteria, however, may result in missing the true peak 5 min epoch, as this may occur between the pre-determined, discrete 5 min epochs. Consequently, matches were analysed using successive 5 min epochs (0-5 min, 1-6 min, 2-7 min, etc.) for the identification of the most intense 5 min epoch.

Information recorded included total distance (TD), metres per min (m/min), relative high speed running distance (HSR), relative high speed efforts (HSReff), relative very high speed running distance (VHSR), relative very high speed efforts (VHSReff) and relative sprint distance (S). As noted by Harley et al. (2010) when classifying player motion speed zones, thresholds should be assessed relative to the individuals speed capabilities, with one method being the assessment of maximal velocity obtained during a 20 m sprint. As a result, maximal linear velocity was defined as the maximal velocity obtained during a 20 m straight line sprint from a standing start and obtained from the individual players’ GPS devices, which were then used to record the individual player’s physical performance, using relative thresholds, during soccer match-play. The 20 m straight line sprints were performed as part of the pre-season fitness testing battery (immediately prior to the commencement of this study) employed within the Academy, in which an appropriate warm-up was administered prior to testing. The warm-up consisted of 5 min of dynamic exercise followed by 5 min of dynamic stretches and two trial sprints, however, the environmental factors were not recorded during sprint testing. Research has suggested that distances in the region of 20-30 m are necessary to accurately assess players’ maximal sprint speed in youth populations (Buchheit, Simpson, Peltola & Mendez-Villanueva, 2012), however, previous research from Harley et al. (2010) adopted the same 20 m sprinting protocol, as within the current study, when assessing maximal sprint speed in highly trained youth soccer players. Relative HSR running was regarded as distance covered above 50% of maximal linear velocity, relative VHSR was regarded as any distance covered above 70% of maximal linear velocity and relative Sprint as anything above 90% maximal linear velocity. The same thresholds were used for HSReff and VHSReff and an effort was regarded as any occurrence when such a speed was attained and sustained for greater than 0.2s.

**Statistical Analysis**

Partial correlations, controlling for maturation using Tanner Stage, between $\dot{VO}_2$ kinetics and physical soccer-based measures were performed on the whole sample. To aid interpretation of the results, confidence intervals
(90%) for correlations were calculated and the magnitude of the correlations were determined using the modified scale by Hopkins (http://www.sportsci.org/resource/stats/, 2000): $r < 0.1$, trivial; $0.1-0.3$, small; $0.3-0.5$, moderate; $0.5-0.7$, large; $0.7-0.9$, very large; $>0.9$, nearly perfect; and 1 perfect). Following this, an intra-group comparison was conducted using independent $t$-tests, with performance in the maximal YoYo-IR1 being used as the criterion variable (Below Average (BA) $n = 9$, Above Average (AA) $n = 8$), as the Yo-Yo IR1 has been shown to be a valid and reliable test with discriminative ability in prospective youth soccer players (Markovic & Mikulic, 2011).

Performance variables between groups were compared using Cohen’s $d$ effect sizes (ES) and thresholds (<0.5 = small; 0.5-0.8 = moderate; >0.8 = large; Cohen, 1988) and reported where appropriate. Additionally, where appropriate a qualitative descriptor, used to aid practical inferences, will be assigned to the following quantitative chances of benefit: 25-75% = benefit possible; 75-95% = benefit likely; 95-99% = benefit most likely; >99% = benefit almost certain (Hopkins, 2000). All statistical analysis was performed using SPSS version 21.0 (IBM SPSS statistics for Windows, IBM, Armonk, New York) and Microsoft Excel (Microsoft Excel 2013, Microsoft, Redmond, Washington) with the level of significance (alpha) set at 0.05.

Results

A representative plot of the oxygen uptake response during the work-to-work protocol is shown in figure 1. Moderate inverse correlations were found between the time constant of $VO_2$ kinetics during the transition to moderate intensity exercise (unloaded – moderate $tau$) with both field measurements that are associated with physical soccer performance, and relative high intensity activity (HSR & VHSR) during soccer match-play (Table 2). However, no relationships were found between measures of $VO_2$ kinetics, from the moderate – severe transitions and the maximal Yo-Yo IR1 test or measurements obtained during soccer match-play. Furthermore, partial correlations between unloaded – moderate $tau$ and peak 5 min HSR revealed no relationships, partial correlations between unloaded – moderate $tau$ and 5 min HSR match averages revealed significant and moderate inverse correlations (Fig 2a & 2b). Additionally, players’ performance in the maximal Yo-Yo IR1 was found to be significantly related to several measures of physical performance during soccer match-play (Table 3).

![Figure 1](image1.png)

![Table 2](image2.png)
Fig 2 * P < 0.05, Partial correlations between unloaded – moderate tau and HSR (m) during A) peak 5 min epoch B) match average 5 min epoch

*** Insert Figure 2a & 2b Here ***

***Insert Table 3 Here***

Intra-group analysis between AA and BA groups revealed differences (moderate to large Cohen’s $d$ effect sizes) between groups in multiple physical measures during: soccer match-play, field testing and measures of both $V_\text{O}_2$ kinetics and $V_\text{O}_2\text{max}$ (Table 4a & 4b). With regards to physical measures during soccer-play, only peak 5 min HSR was shown to be ‘unclear’ between groups (according to Hopkins’ (2000) classifications), despite a moderate effect size. With respect to laboratory based measures only $V_\text{O}_2\text{max}$ was shown to be significantly larger in the AA group, however, the $tau$ for pulmonary oxygen uptake kinetics during the transition to moderate intensity exercise was faster in the AA group, revealing a large effect size and ‘likely positive’ inference between groups.

***Insert Table 4a & 4b Here***

Discussion

The main finding of the present study was that there was a significant inverse relationship between the time constant ($tau$) for oxygen uptake kinetics during the transition from unloaded - moderate intensity exercise and the amount of high intensity activities performed during soccer match-play as well as performance in the Yo-Yo IR1. Furthermore, analysis of 5 min epoch match averages revealed significant inverse relationships between unloaded – moderate $tau$ and relative HSR. Finally, results from the intra group analysis revealed that players who performed above average in the Yo-Yo IR1 test demonstrated superior performance in both laboratory tests (unloaded – moderate $tau$ and $V_\text{O}_2\text{max}$) and physical performance during soccer match-play (Table 4a & 4b).

To the authors’ knowledge this is the first study to examine the impact of measures of $V_\text{O}_2$ kinetics, along with measures of $V_\text{O}_2\text{max}$, upon variables of physical performance obtained during soccer match-play, in a group of highly trained youth soccer players. As a result, the present study extends and improves upon existing research via examining the relationship between $tau$, along with $V_\text{O}_2\text{max}$, on measures of physical soccer performance in a group of highly trained youth soccer players, during both a standardised test (Yo-Yo IR1) and during soccer
match-play, using GPS technology. Consequently, this study attempted to adopt a more ecologically valid approach to evaluating physical soccer performance in relation to measures of VO\textsubscript{2} kinetics. This was achieved by assessing players’ physical performance during soccer match-play, rather than the sole use of a surrogate indicator of physical soccer performance (e.g. Yo-Yo IR1). Using this innovative approach, present results have revealed that measures of high intensity activity, obtained during soccer match-play are inversely related to \(\tau\), during an unloaded to moderate transition. This supports previous work in both adults and adolescent populations. Firstly, Rampinini et al. (2010) demonstrated that professional adult soccer players demonstrated a faster \(\tau\) (from unloaded to moderate transitions) when compared to amateur soccer players (27.2 ± 3.3 vs. 32.3 ± 5.7 s). Secondly, soccer trained male adolescents have been shown to present faster VO\textsubscript{2} kinetics (from unloaded to moderate transitions) when compared to untrained but recreationally active participants (\(\tau\): 22.3 ± 7.2 vs. 29.8 ± 8.4 s) (Marwood et al., 2010). A finding which is also evident within female adolescent soccer players, when compared to untrained but recreationally active participants (\(\tau\): 26.3 ± 6.9 vs. 35.1 ± 11.5 s) (Unnithan et al., 2015). Current findings, however, expand upon previous research by highlighting the impact of superior VO\textsubscript{2} kinetics upon key measures of physical soccer performance (e.g. HSR activity), during match-play and within a group of highly trained youth soccer players. Consequently, as levels of high intensity activity have been shown to be a distinguishing factor of superior soccer performance (Mohr, Krustrup & Bangsbo 2003), an improved ability to accommodate the necessary energy demands, during soccer match-play, via superior VO\textsubscript{2} kinetics and utilisation of aerobic pathways may result in a greater accumulation, frequency and maintenance of high intensity activity.

Within the assessment of players’ physical performance during soccer match-play, a secondary aim was to assess the impact of VO\textsubscript{2} kinetics on players’ physical performance during the peak 5 min epoch, post-peak 5 min epoch and the match average 5 min epochs. Results demonstrate that while measures of VO\textsubscript{2} kinetics, during an unloaded – moderate and moderate – severe transition, have little influence upon the amount of high intensity activity performed over a short period of time (peak 5 min) or in the subsequent 5 min period (post-peak 5 min), measures of unloaded-moderate \(\tau\) were significantly related to 5 min epoch match averages for measures of HSR, with a faster unloaded – moderate \(\tau\) equating to a greater 5 min epoch match average for HSR. Thus, there is evidence to suggest that measures of VO\textsubscript{2} kinetics, particularly unloaded - moderate \(\tau\), may have a significant impact upon the maintenance and the ability to sustain levels of high intensity activity over a prolonged period of time.
(20 - 40 min), during competitive soccer match-play. This is in line with Dupont et al. (2005), who reported a significant relationship between the phase II tau, during a low to moderate transition, and the percentage decrement in speed during 15 repeated 40 m maximal sprints, with 25 s of active recovery. Together, these results demonstrate that when numerous bouts of repeated high intensity activity are required, superior VO2 kinetics are potentially advantageous to performance via a greater tolerance to mechanisms of fatigue (Buchheit, Abiss, Peiffer & Laursen, 2012; Dupont et al., 2005). However, the exercise prescribed in the study by Dupont et al. (2005) greatly exceeds the work that would be experienced during an intense 5 min period of competitive soccer match-play. Rather, the volume of work prescribed by Dupont et al. (2005) is indicative of the amount of work performed during a prolonged period of competitive soccer match-play. Nevertheless, current findings suggest that, while measures of VO2 kinetics, during an unloaded to moderate transition, may not have an impact upon the high intensity activity over a short period of time (5 min) during competitive soccer match-play, they do have an increasing influence over a prolonged period of time. This suggests that superior VO2 kinetics preserve and help to maintain intermittent high intensity activity during sustained periods of soccer match-play, a finding which may be linked to the enhanced ability to activate the more sustainable aerobic energy sources.

While the present results provide some evidence for the relationship between physical measures associated with superior soccer performance and VO2 kinetics, the complex physiology involved during high-intensity intermittent exercise should be acknowledged. As a result research in this area has produced equivocal results, with some studies finding little or no relationship between VO2 kinetics and intermittent exercise performance (Buchheit, Hader & Mendez-Villanueva, 2012; Christensen et al., 2011; Wells et al., 2012) and other studies demonstrating significant associations between superior VO2 kinetics and intermittent exercise capacity (Dupont et al., 2005; Rampinini et al., 2009; Rampinini et al., 2010). Performance during high-intensity intermittent exercise, like that which is experienced during soccer match-play, is a product of complex interactions between metabolic, cardiorespiratory and cardiovascular issues. Indeed, factors such as transportation of ions, metabolite accumulation, muscle excitability and muscle oxygenation (Girard, Mendez-Villanueva & Bishop, 2011) among numerous other factors will impact upon the presence of fatigue, and therefore the level of physical performance during soccer match-play (Bangsbo et al., 2006).
Consequently, one variable (e.g. \( \tau \) or \( VO_{2\max} \)) will not, on its own, predict players’ intermittent exercise capacity, as is evidenced by the correlational statistics provided within the present study. Furthermore, the finding that the AA Yo-Yo group performed significantly more HSR and VHSR than the BA group, despite there being no significant difference in measures of \( \tau \), supports the fact that performance during high-intensity intermittent exercise is multifaceted. Nevertheless, the current results provide an indication to the contribution of the energy systems during youth soccer match-play, demonstrating that a faster \( \tau \), during an unloaded to moderate transition, was associated to the accumulation, frequency and maintenance of high intensity activity during soccer match-play. Additionally, current results reinforce the adoption of the Yo-Yo IR1 test as an appropriate test for assessing sport-specific fitness levels in highly trained youth soccer players.

Therefore, methods of training which are capable of speeding up \( \tau \), should improve the accumulation, frequency and maintenance of high intensity activity during soccer match-play, in highly trained youth soccer players. Indeed, high intensity conditioning drills or the use of game-based training drills (e.g. small sided games), which are designed to provide sustained periods (3 - 4min) at an intensity >85% HR\(_{\text{max}}\), at a work to rest ratio of 2:1, may be incorporated as a stimulus to enhance players’ aerobic capacity and subsequently improve measures of \( VO_{2} \) kinetics. Similarly, the use of supra-maximal repeated sprint drills or drills which require a player to work above their maximal aerobic speed for shorter intervals may be also utilised as a conditioning method for improving players’ \( VO_{2} \) kinetics (Buchheit & Laursen, 2013).

There were no statistically significant relationships between measures of \( VO_{2} \) kinetics (\( \tau \)) during the moderate to severe transitions and any of measures associated with physical soccer performance. Current findings are supported by those of Nyberg et al. (2016), who reported no change in measures of \( VO_{2} \) kinetics during a moderate (10 km/h) to severe (16 km/h) transition in highly trained adult soccer players, following a period of additional speed endurance training. This was despite significant improvements in Yo-Yo IR1 performance (11.6 ± 6.4%) and pulmonary \( VO_{2} \) kinetics during an unloaded to moderate transition (11.4 ± 16.5%) (Nyberg et al., 2016).

In addition, the current results show a large standard deviation is apparent for measures of \( \tau \) during the moderate - severe transition, these large variations in \( \tau \) may be a result of the intensity prescribed for severe exercise (60%Δ). The prescribed intensity of 60%Δ, despite being a relative intensity, is likely to be in the proximity of critical speed (Burnley & Jones, 2007; Ozyener, Rossiter, Ward & Whipp, 2001), resulting in some individuals
being above their critical speed and some being below. As a result, this may have elicited different physiological
responses across the current sample. The times recorded, however, for time to exhaustion during the severe
intensity (551.6 ± 167.5 s) provide support that all players were performing at an intensity above their critical
speed. Nevertheless, the prescribed intensity may have resulted in some individuals not being able to maintain
their performance for a satisfactory amount of time, thus affecting the ‘fit’ of the \( \text{VO}_2 \) response. As noted by
Ozyener et al. (2001) the \( \text{VO}_2 \) kinetics during dynamic muscular exercise are clearly influenced by the exercise
intensity. Research also suggests there is a reduced \( \text{VO}_2 \) amplitude in the slow component when running compared
to cycling exercise (Carter et al., 2000; Jones & McConnell, 1999). Furthermore, the breath-to-breath noise has
been shown to be large in child populations (Potter, Childs, Houghton & Armstrong, 1998) while the amplitude
of the \( \text{VO}_2 \) slow component has been shown to be small in child populations (Williams et al., 2001). This can
result in low signal to noise properties within the \( \text{VO}_2 \) profiles and impact upon the fitting of the moderate - severe
transition, making it difficult to reliably identify the non-steady state ‘phase’ of the \( \text{VO}_2 \) response during this
transition (Armstrong & Barker, 2009). To date, there is limited knowledge as to whether or not trained individuals
actually present faster \( \text{VO}_2 \) kinetics during work-work transitions and, therefore, the applicability of \( \text{VO}_2 \) kinetics
profiles obtained during a moderate to severe transition and their relationship to physical soccer performance
requires further research. Although, initial results from the current study and that of Nyberg et al. (2016) would
seem to indicate that the \( \text{VO}_2 \) kinetics profile obtained from a moderate to severe transition is unrelated and not
influenced by the high-intensity intermittent exercise that is experienced during soccer match-play.

Previous research that has examined the relationship between \( \text{VO}_2 \) kinetics and physical measures associated with
soccer match-play has failed to provide physical data from performance during competitive soccer match-play.
The addition of such information will improve the ecological validity and application of measures obtained from
both laboratory and field tests to team sports performance. It is understood, however, that reasonable levels of
game to game variation exist within soccer match-play (Gregson et al., 2010). Indeed, Gregson et al. (2010)
reported high levels of variance for HSR (CV = 16.2 ± 6.2%) during elite adult competitive football when
analysing players’ physical performance across two seasons. Information regarding the variance in physical
performance, for youth soccer players is lacking, however, analysis of the variance across the three matches
employed within the current study revealed typical errors of 4.3 m/min for TD, 316 m & 24 efforts in the HSR
threshold and 75 m & 5 efforts in the VHSR threshold. While the values presented are substantial, when applied
in relation to the data reported for the AA and BA groups, within the current study, the difference between groups is in excess of the typical errors presented.

In previous research, the resultant impact of the opposing team (Gabbett, 2013), phase of the season (Gregson et al. 2010; Kempton, Sullivan, Bilsborough, Cordy & Coutts, 2015), weather conditions, substitutions, context of the match (win/lose margin) and current form (Black & Gabbett, 2014) are all likely to have an influence on players’ physical performance and need to be considered when analysing players’ physical performance during soccer match-play. Nevertheless, the current procedures controlled for the composition of players, positions and teams as well as the playing surface and playing time, in an attempt to reduce the variance from game-to-game.

Finally, the potential impact of growth and maturation should not be ignored when assessing youth soccer players. In the present study, however, the effects of growth and maturation upon the fitness components measured was equivocal. Indeed, no relationships between maturation status, measured via Tanner Stage and Maturity Offset, were found between measures of VO2 kinetics and measures associated with physical performance during soccer match-play. Although, the limitations of the adopted methods used to assess growth and maturation do need to be acknowledged. Firstly, the Tanner stage method of maturation does not provide information on the point at which a player entered a particular stage of maturation or how long an individual has been in a particular stage of maturation (Malina et al., 2012). Secondly, the accuracy of the predictive equation used to determine the maturity offset has been shown to decrease the further the individual is away from the period of peak height velocity (Malina, Cumming, Morano, Barron & Miller, 2005). Nevertheless, the impact of growth and maturation within the current sample, particularly during the intra-group analysis, was negligible. Furthermore, partial correlations were employed throughout to control for any possible influence of growth and maturation. Despite these limitations the current study extends and improves upon the existing research by examining distinct measures of cardio-respiratory fitness in relation to measures of physical performance obtained during soccer match-play in elite youth soccer players.

**Conclusion**

The results from this study demonstrate that players with a superior ability to activate aerobic energy pathways at the onset of exercise, evidenced by a faster tau during transitions from low to moderate intensity exercise, tend to perform better in Yo-Yo IR1 and perform a greater amount of relative HSR during soccer match-play. Hence, the
accumulation, maintenance and frequency of high intensity activity during competitive soccer match-play, in highly trained youth soccer players, are associated with a faster $\tau$ during an unloaded to moderate exercise transition but unrelated to $\tau$ during a moderate – severe exercise transition. This study demonstrates that measures obtained from $V\text{O}_2$ kinetics testing protocols may be of benefit when assessing youth players’ physical performance during soccer match-play and could therefore be used as a measure to distinguish those of superior physical performance. Based on these findings, the physiological capacity to transition rapidly between workloads, particularly from low – moderate intensities, is a potential determinant of superior physical performance (specifically high intensity activities), during soccer match-play, in highly trained youth soccer players.

References


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