



25 **Abstract**

26 **Purpose:** To examine the relationship between oxygen uptake kinetics ( $VO_2$  kinetics) and physical measures  
27 associated with soccer match-play, within a group of highly trained youth soccer players.

28 **Methods:** Seventeen highly trained youth soccer players (age:  $13.3 \pm 0.4$  yr, self-assessed Tanner Stage:  $3 \pm 1$ )  
29 volunteered for the study. Players initially completed an incremental treadmill protocol to exhaustion, to establish  
30 gaseous exchange threshold (GET) and  $VO_{2max}$  ( $59.1 \pm 5.4$  mL $\cdot$ kg $^{-1}$  $\cdot$ min $^{-1}$ ). On subsequent visits players completed  
31 a step transition protocol from, rest–moderate intensity exercise, followed by an immediate transition from  
32 moderate–severe intensity exercise (moderate: 95%GET, severe: 60% $\Delta$ ), during which  $VO_2$  kinetics were  
33 determined. Physical soccer-based performance was assessed using a maximal Yo-Yo Intermittent Recovery test  
34 level 1 (Yo-Yo IR1) and via GPS derived measures of physical soccer performance during soccer match-play, 3  
35 2 x 20min, 11 v 11 matches, to gain measures of physical performance during soccer match-play.

36 **Results:** Partial correlations revealed significant inverse relationships between the unloaded to moderate transition  
37 time constant ( $\tau$ ) and: Yo-Yo IR1 performance ( $r = -0.58$ ,  $P = 0.02$ ) and GPS variables (Total distance (TD):  $r$   
38  $= -0.64$ ,  $P = 0.007$ , High speed running (HSR):  $r = -0.64$ ,  $P = 0.008$ , High speed running efforts (HSReff):  $r = -$   
39  $0.66$ ,  $P = 0.005$ ).

40 **Conclusion:** Measures of  $VO_2$  kinetics are related to physical measures associated with soccer match-play and  
41 could potentially be used to distinguish between those of superior physical performance, within a group of highly-  
42 trained youth soccer players.

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47 **Key Words:** Team Sports, Intermittent Exercise, Youth Soccer,  $VO_2$  Kinetics

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**Abbreviations:**


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GET	Gaseous exchange threshold
GPS	Global positioning system
HSR	High speed running
HSReff	High speed running efforts
RER	Respiratory exchange ratio
<i>tau</i>	Time constant
TD	Total distance
VHSR	Very high speed running
VHSReff	Very high speed running efforts
VO <sub>2</sub> kinetics	Oxygen uptake kinetics
VO <sub>2max</sub>	Maximal oxygen consumption
Yo-Yo IR1	Yo-Yo intermittent recovery level 1 test

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55 **Introduction**

56 The contribution of aerobic metabolism during soccer match play is dominant, accounting for up to 90% of the  
57 energy required (Iaia, Rampinini & Bangsbo, 2009). However, as a consequence of the numerous, discrete high  
58 intensity actions incurred throughout competitive match-play (Bangsbo, Mohr & Krstrup, 2006), the contribution  
59 of anaerobic energy pathways is likely to be high at certain points during the game. The ability to perform, repeat  
60 and sustain high intensity exercise is essential for elite soccer performance (Iaia et al., 2009). Consequently, faster  
61 oxygen uptake kinetics (VO<sub>2</sub> kinetics) during transitions from low to high intensity exercise could preserve the  
62 capacity of the anaerobic energy systems and thus enhance an individual's tolerance to fatigue (Glaister, 2005).  
63 In addition, faster VO<sub>2</sub> kinetics could result in a higher total energy turnover during high intensity exercise, when  
64 added to maximal anaerobic energy turnover. Therefore, resulting in the ability to maintain, repeat and sustain  
65 high intensity exercise during soccer match-play.

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67 Global measures of aerobic capacity, like maximal oxygen consumption (VO<sub>2max</sub>), have been examined in relation  
68 to measures of physical soccer performance (Rebelo, Brito, Seabra, Oliveira & Krstrup, 2014). Measures of

69  $VO_{2max}$ , however, have shown an inability to distinguish between players of the same playing level (Rampinini et  
70 al., 2010; Stroyer, Hansen & Klausen, 2004) and is less sensitive to training when compared to the Yo-Yo IR1 &  
71 IR2 tests, which are measures of intermittent running capacity (Bangsbo, Iaia & Krstrup, 2008). Measures of  
72  $VO_2$  kinetics, therefore have been proposed as an alternative determinant of sports performance (Burnley & Jones,  
73 2007). For example, while Rampinini et al (2010) reported no significant differences in measures of  $VO_{2max}$   
74 between professional and amateur adult soccer players, the professional soccer players were shown to possess  
75 faster  $VO_2$  kinetics than their amateur counter-parts, as measured by the time constant of the transition to moderate  
76 intensity exercise ( $27.2 \pm 3.3$  vs.  $32.3 \pm 5.7$  s). Furthermore, Rampinini et al. (2010) demonstrated that the time  
77 constant from rest to moderate intensity exercise, was 'largely' related to both the Yo-Yo IR1 ( $r = -0.60$ ) and Yo-  
78 Yo IR2 ( $r = -0.65$ ). Whether this effect has an impact on soccer match-play or is apparent within a cohort of highly  
79 trained youth soccer players is yet to be investigated.

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81 Research within adult populations has produced equivocal findings, with some studies demonstrating significant  
82 associations between superior  $VO_2$  kinetics and intermittent exercise capacity (Dupont et al., 2005; Rampinini et  
83 al., 2009; Rampinini et al., 2010), while others have reported no association between the two (Buchheit, Hader &  
84 Mendez-Villanueva, 2012; Christensen et al., 2011; Wells et al., 2012). Research in both male and female  
85 adolescents, however, has demonstrated faster  $VO_2$  kinetics in soccer trained individuals in comparison to their  
86 untrained counterparts (Marwood et al., 2011; Unnithan, Roche, Garrard, Holloway & Marwood, 2015).  
87 Consequently,  $VO_2$  kinetics may impact upon measures of physical soccer performance during elite youth soccer  
88 match-play. Previous studies, however, have limited applicability to performance during soccer match-play as  
89 they only compared untrained and trained participants  $VO_2$  kinetics during laboratory controlled treadmill exercise  
90 and did not relate this to performance during soccer match-play. As a result, while soccer trained individuals have  
91 been shown to demonstrate superior  $VO_2$  kinetics when compared to untrained or amateur athletes, it is unclear  
92 to what extent measures of  $VO_2$  kinetics are related to physical measures of performance, obtained during soccer  
93 match-play, within a group of highly-trained adolescent soccer players.

94

95 Initial research examining  $VO_2$  kinetics in soccer have assessed  $VO_2$  kinetics using a single square-wave transition  
96 (unloaded – moderate intensity) protocol (Rampinini et al., 2010; Marwood et al., 2011; Unnithan et al., 2015).  
97 Soccer match-play, however, incorporates severe intensity exercise which is often initiated from an elevated

98 baseline work rate ( $VO_2$ ), resulting in the recruitment of higher order motor units (preferential recruitment of type  
99 II muscle fibres) (Nyberg et al., 2016). Consequently, in order to mimic these soccer-specific workload transitions,  
100 a novel methodological approach was used by Nyberg et al. (2016). These authors utilised a double-step exercise  
101 protocol, when examining the impact of additional speed endurance training on Yo-Yo IR1 performance, in highly  
102 trained adult soccer players. The examination of  $VO_2$  kinetics profiles during a step transition, work-to-work  
103 protocol (unloaded – moderate and moderate - severe) therefore allows for a more representative test in a soccer-  
104 specific cohort and provides a novel means for examining  $VO_2$  kinetics in relation to the demands that are  
105 presented during soccer match play. As a result, the purpose of this study was to examine the relationship between  
106  $VO_2$  kinetics, during a step transition work-to-work protocol, and measures of physical performance obtained  
107 during soccer match-play, within a group of highly trained youth soccer players. It was hypothesised that those  
108 players who demonstrate faster pulmonary  $VO_2$  kinetics during both transitions (unloaded – moderate & moderate  
109 – severe) would also demonstrate superior measures of physical performance during soccer match-play.

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## 111 **Methods**

### 112 *Participants*

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

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122 **\*\*\* Insert Table 1 Here\*\*\***

123

### 124 *Study Design*

125 Data collection was conducted over a three-week period at the beginning of a competitive season (pre-season) at  
126 a period where there were no competitive matches; during this period laboratory and field tests were conducted.

127 The players visited the laboratory on 3 separate occasions, performed a field test (Yo-Yo IR1) and were involved  
128 in three 11 v 11 matches (including the same pitch dimensions, the same composition of players in the same  
129 positions and the same coaches, excluding goalkeepers from the analysis). During the periods of laboratory testing,  
130 training only consisted of light technical practices, however, recovery periods of 24 hours were implemented  
131 between all laboratory tests. In the first laboratory visit, players performed an incremental, ramp treadmill protocol  
132 for the assessment of players' gaseous exchange threshold (GET) and  $VO_{2max}$ . Players returned to the laboratory  
133 on two further occasions. These two, separate visits to the laboratory were identical and required the participant  
134 to complete a step transition protocol (from rest - moderate exercise, followed by an immediate transition from  
135 moderate - severe intensity exercise) on a motorised treadmill for the assessment of their pulmonary oxygen  
136 uptake kinetics. All testing was completed at the same time of day ( $\pm 2$  hours), with room temperature, humidity  
137 and pressure corresponding to  $20.5 \pm 1.5$  °C,  $61.0 \pm 1.4$  % and  $1016 \pm 3$  mmHg respectively, for laboratory testing.

138

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

145

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

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157 *Assessment of Maximal Oxygen Uptake and Gaseous Exchange Threshold*

158 Upon arrival at the laboratory and following pre-participation screening procedures (including completion of  
159 training and health questionnaires as well as the assessment of players' resting heart rate and blood pressure),  
160 participants were fitted with a Polar Heart rate monitor (Polar Electro, Kempele, Finland) and face-mask (Hans  
161 Rudolph, Hans Rudolph, Kansas City, USA), which was connected to an online gas analysis system (Cortex  
162 MetaMax 3B, Cortex Biophysik GmbH, Leipzig, Germany). The online gas analyser was calibrated prior to each  
163 visit according to the manufacturer's instructions, using a known gas concentration and a 3-L syringe for manual  
164 volume calibration of the ventilation sensors. Following a standardised 10 min warm up and a full description of  
165 the test and safety procedures, participants began to run at a speed of 8 km/h at a 1 % incline (Jones & Doust,  
166 1996) on a motorised treadmill (HP Cosmos, Pulsar, Sportgerate GmbH, Nussdorf, Germany). The speed of the  
167 treadmill was increased by 1 km/h<sup>-1</sup> every two minutes, this continued until participants reached 90% of their age  
168 predicted heart rate max (207 – (0.7 x age)) (Gellish et al., 2007). At this point, the treadmill speed remained  
169 constant whilst the incline of the treadmill was increased by 1% every minute until volitional exhaustion; this  
170 procedure was employed to avoid over-striding and potential early termination and inaccurate assessment of  
171 participant's  $VO_{2max}$ . This method has been successfully used before to elicit  $VO_{2max}$  during treadmill running in  
172 young populations (Williams, Carter, Jones & Doust, 2001).  $VO_{2max}$  was taken as the highest 15 sec average  
173 during the test (Astorino, Robergs, Ghiasvand, Marks & Burns, 2000). Test criteria for a maximal effort, were the  
174 achievement of at least two of the following three performance values: 1) respiratory exchange ratio (RER) above  
175 1.00, 2) plateau in  $VO_2$  despite an increasing speed (increase in  $VO_2$  of < 2 mL·kg<sup>-1</sup>·min<sup>-1</sup>) 3) heart rate ±10  
176 beats/min of age predicted maximal heart rate (Cooke, 2009). The incremental, ramp treadmill protocol resulted  
177 in 100% percent of the participants reaching an RER value of greater than 1.00 and a heart rate value within ±10  
178 beats/min of age predicted maximal heart rate, while 88% of the participants presented a plateau in  $VO_2$  despite  
179 an increase in speed. It has previously been shown, however, that only a minority of children present a plateau in  
180  $VO_2$  during treadmill exercise (Armstrong & Welsman, 1994) and that children can exercise to exhaustion during  
181 incremental exercise without exhibiting a  $VO_2$  plateau (Welsman & Armstrong, 1996). Therefore, as all  
182 participants achieved two of the stated criteria and the presence of a  $VO_2$  plateau is not commonly exhibited in  
183 children, the term  $VO_{2max}$  was adopted throughout.

184

185 The gaseous exchange threshold (GET) was identified using the V-slope method ( $V\dot{C}O_2$  (ordinate),  $VO_2$  (abscissa)  
186 (Beaver, Wasserman & Whipp, 1986). Two regression lines were created based upon the relationship between  
187  $V\dot{C}O_2$  and  $VO_2$ . The intercept point between the two regression lines was then visually identified, with the  $VO_2$   
188 value at the intercept (GET) being extrapolated to the abscissa. To identify the speed at GET, a regression equation  
189 was formulated for  $VO_2$  and running velocity, for each individual. The individual's  $VO_2$  at GET was then inputted  
190 into the individual's respective regression equation to calculate the running velocity at GET. The V-slope method  
191 has been shown to be a viable and reliable method for detecting and identifying the gaseous exchange threshold  
192 in children (Fawkner, Armstrong, Childs & Welsman, 2002; Unnithan, Timmons, Paton & Rowland, 1995). The  
193 GET was assessed by two individual researchers (experienced in the detection of GET), demonstrating 82%  
194 agreement (14 out of 17). For the remaining three participants, a third researcher, also experienced in the detection  
195 of GET, was approached to verify the GET. Following this test, the treadmill speed corresponding to 95% GET  
196 and 60% of the difference between GET and  $VO_{2max}$  ( $60\%\Delta$ ) were calculated for each individual.

197

#### 198 *Assessment of pulmonary oxygen uptake kinetics*

199 On the two remaining visits to the laboratory, each participant completed two transitions for each change in  
200 workload (unloaded – moderate and moderate – severe), meaning the  $VO_2$  response was averaged from two  
201 transitions. Previous research has demonstrated that acceptable confidence intervals for  $\tau$  when averaging the  
202  $VO_2$  response from two transitions (Marwood et al., 2011; Unnithan et al., 2015). The work-to-work kinetics  
203 protocol consisted of 3 min unloaded (standing), 4 min running at a speed equivalent to 95% GET (moderate  
204 intensity) and a run to exhaustion at a speed equivalent to  $60\%\Delta$  (severe intensity). Prior to the test, participants  
205 were fitted with a Polar heart rate monitor and face mask, which was connected to an online expired gas analysis  
206 system. Participants were also familiarised with the transition to each speed and given sufficient time to practise  
207 until they felt comfortable with both transitions (unloaded – moderate and moderate – severe). Participants ran  
208 for no longer than 5 sec at the higher intensities during familiarisation. Following familiarisation to the speed  
209 transitions, participants rested, allowing their heart rate to return to pre-exercise values, before commencing the  
210 test. During the test, verbal encouragement was provided throughout for participants to continue for as long as  
211 possible, however no visual feedback relating to exercise duration was given to the participants during the test.

212



213 For the unloaded to moderate transition the treadmill was set at the relevant intensity (95% GET; average = 10.4  
214  $\pm$  1.0 km/h, range = 8.8 – 12.2 km/h) for each individual, while the participant straddled the treadmill. The  
215 participant was then given a 10 second countdown at the end of the unloaded phase, at which point they lowered  
216 themselves onto the moving treadmill and began exercising. For the transition from moderate to severe intensity  
217 the participant remained running on the treadmill. The time taken for each exercise transition was in all cases < 5  
218 seconds, thus having minimal effects on the  $VO_2$  kinetic response as this would be contained within the  
219 cardiodynamic phase of the oxygen uptake response to an increase in intensity (Whipp & Rossiter, 2005).

220

### 221 *Mathematical modelling of oxygen uptake kinetics*

222 Prior to the modelling of the  $VO_2$  kinetics errant breaths (coughing, swallowing, sighing, etc.) were removed from  
223 the raw data set so as not to distort or skew the underlying physiological response. Errant breaths were defined as  
224 a breath that was different to the mean of the surrounding four breaths by more than four times the standard  
225 deviation of the same surrounding four data points (Jones & Poole, 2005, Marwood et al., 2011). Both data-sets  
226 from each stage (unloaded – moderate and moderate – severe) were time aligned and ensemble averaged to  
227 enhance the underlying physiological response characteristics for all intensities. Each ensemble average was then  
228 linearly interpolated second-by-second prior to the modelling process. Custom written software in Microsoft  
229 Excel, using the Solver function, was utilised for all modelling processes.

230

231 Pulmonary oxygen uptake kinetics for the unloaded - moderate and moderate - severe transitions were modelled  
232 separately, due to the difference in the characteristics of the kinetic response for each increase in intensity. For  
233 both, unloaded – moderate and moderate – to severe transitions, the goal of the modelling process was to isolate  
234 the fundamental phase (Whipp & Rossiter, 2005) of  $VO_2$  kinetic response (equation 1). To eliminate the influence  
235 of the cardiodynamic phase on the modelling of  $VO_2$  kinetics, the initial 20 seconds from the unloaded to moderate  
236 phase and initial 15 seconds of the moderate to severe phase were removed prior to the modelling process. A time  
237 delay of 20 seconds is often employed to accommodate the cardiodynamic phase (Whipp & Rossiter, 2005);  
238 however, a 15 second time delay was adopted for the moderate to severe transition due to elevated baseline blood  
239 flow incurred from the prior moderate intensity (Buchheit, Laursen & Ahmaidi, 2009). Following the  
240 cardiodynamic phase,  $VO_2$  kinetics were assumed to develop initially via a single exponential term (fundamental  
241 phase), following a delay relative to the start of exercise of the form:

242

$$V_{O_{2(t)}} = V_{O_{2(b)}} + A_{VO_2} \cdot (1 - \exp^{-(t-TD)/\tau}) \quad [1]$$

244

245 Where  $V_{O_{2(b)}}$  is the baseline  $VO_2$ , which was taken as the last 30 seconds of oxygen uptake during 3 minutes  
 246 unloaded phase or steady state value of moderate for mod – severe transition.  $A_{VO_2}$  represents the asymptotic  
 247 amplitude of the fundamental component of the response;  $\tau$  is the time constant of the fundamental component  
 248 and  $TD$  is the time delay similar, but not equal to the cardiodynamic-fundamental phase transition time. For the  
 249 unloaded – moderate transition, the fundamental phase was considered *a priori* to encapsulate the entire 4-minute  
 250 transition since exercise was undertaken below the GET. For the moderate – severe transition, the fitting strategy  
 251 was designed to identify the onset of the “slow component” of the response to exercise, and thus isolate the  
 252 fundamental component. Starting at 60 s, the fitting window was therefore widened by 1 s until the end of exercise  
 253 with the time constant and reduced chi-square value of the curve of best fit for each time window plotted against  
 254 time. The onset of the slow component could then be identified as the coincident point at which a plateau or  
 255 minima in the value of  $\tau$  and a minima in chi-square, followed by a progressive increase in these values, could be  
 256 determined as its value becomes affected by the slow component. The time at which this occurred was used as  
 257 the optimal fitting window with which to determine the kinetics of the fundamental phase of  $VO_2$  kinetics. The  
 258 phase III (Whipp & Rossiter, 2005) of oxygen uptake (steady state in the unloaded – moderate transition) was  
 259 taken as the sum of  $V_{O_{2(b)}}$  and  $A_{VO_2}$ . The amplitude of the slow component during the moderate – severe  
 260 transition was calculated as  $VO_2$  at exhaustion minus the phase III  $VO_2$ .

261

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

263 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-  
 264 Yo IR1 test requires participants to run 2 x 20 m shuttle runs at increasing speeds, interspersed with 10 seconds  
 265 of active recovery. The pace of the test was controlled by audio signals emitted from a CD player (Sony CFD-V7,  
 266 Sony, Tokyo, Japan). For the Yo-Yo IR1 test players were required to run until volitional termination of the test  
 267 or, when they have twice failed to meet the designated cones in time with the audio signal, at which point they are  
 268 removed from the test. The test score is the distance covered at the point they withdraw from the test. During the  
 269 test, players were allowed to consume fluids ad libitum. Current findings support the use of the Yo-Yo IR1 test  
 270 as a valid measure of physical performance in soccer, particularly within youth populations (Bangsbo et al., 2008;

271 Krustrup et al., 2003). All players were familiar with the Yo-Yo IR1, as it is a fitness test regular employed (4  
272 times a season) by the respective Academy.

273

#### 274 ***Monitoring Soccer Match-Play***

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

290

291 Following each match, the GPS data was downloaded and analysed using Catapult Software (Catapult,  
292 Melbourne, Australia) and specially designed Microsoft Excel spreadsheets. Following this an average of the 3  
293 games was calculated for each player for each variable. Data was recorded for the whole match, each 20 min half  
294 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  
295 the peak 5 min epoch (identified as the 5 min epoch with the highest amount of high speed running distance), the  
296 subsequent 5 min epoch to the peak 5 min epoch and the mean of the cumulative 5 min epochs throughout the  
297 match. These were then averaged over the 3 matches. The peak 5 min epoch provides a surrogate measure of the  
298 highest amount of high speed distance that a player can perform within a 5 min period during soccer match-play,  
299 whereas the mean of the cumulative 5 min epochs throughout an entire match provides an indirect measure of a  
300 player's ability to sustain their levels of physical performance during match-play. Finally, the subsequent 5 min

301 epoch following the peak 5 min epoch provides an estimate of a player's ability to 'recover' and maintain their  
302 levels of physical performance, immediately following an exhaustive period of activity. Previous research has  
303 used discrete 5 min epochs (0-5 min, 5-10 min, etc.) to identify the peak 5 min interval during soccer match-play  
304 (Bradley et al., 2009). The adoption of such criteria, however, may result in missing the true peak 5 min epoch,  
305 as this may occur between the pre-determined, discrete 5 min epochs. Consequently, matches were analysed using  
306 successive 5 min epochs (0-5 min, 1-6 min, 2-7 min, etc.) for the identification of the most intense 5 min epoch.

307

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

327

### 328 *Statistical Analysis*

329 Partial correlations, controlling for maturation using Tanner Stage, between  $VO_2$  kinetics and physical soccer-  
330 based measures were performed on the whole sample. To aid interpretation of the results, confidence intervals

331 (90%) for correlations were calculated and the magnitude of the correlations were determined using the modified  
332 scale by Hopkins (<http://www.sportsci.org/resource/stats/>, 2000):  $r < 0.1$ , trivial; 0.1-0.3, small; 0.3-0.5, moderate;  
333 0.5-0.7, large; 0.7-0.9, very large;  $>0.9$ , nearly perfect; and 1 perfect). Following this, an intra-group comparison  
334 was conducted using independent  $t$ -tests, with performance in the maximal YoYo-IR1 being used as the criterion  
335 variable (Below Average (BA)  $n = 9$ , Above Average (AA)  $n = 8$ ), as the Yo-Yo IR1 has been shown to be a valid  
336 and reliable test with discriminative ability in prospective youth soccer players (Markovic & Mikulic, 2011).  
337 Performance variables between groups were compared using Cohen's  $d$  effect sizes (ES) and thresholds ( $<0.5 =$   
338 small;  $0.5-0.8 =$  moderate;  $>0.8 =$  large; Cohen, 1988) and reported where appropriate. Additionally, where  
339 appropriate a qualitative descriptor, used to aid practical inferences, will be assigned to the following quantitative  
340 chances of benefit: 25-75% = benefit possible; 75-95% = benefit likely; 95-99% = benefit most likely;  $>99% =$   
341 benefit almost certain (Hopkins, 2000). All statistical analysis was performed using SPSS version 21.0 (IBM  
342 SPSS statistics for Windows, IBM, Armonk, New York) and Microsoft Excel (Microsoft Excel 2013, Microsoft,  
343 Redmond, Washington) with the level of significance (alpha) set at 0.05.

344

## 345 **Results**

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

356

357 **Fig 1** Representative plot of the pulmonary oxygen uptake kinetics during the work-to-work protocol, with the  
358 respective unloaded - moderate and moderate - severe time constants ( $\tau$ s)

359

360

\*\*\* Insert Figure 1 Here \*\*\*

361

362

\*\*\*Insert Table 2 Here\*\*

363 **Fig 2** \*  $P < 0.05$ , Partial correlations between unloaded – moderate  $\tau$  and HSR (m) during A) peak 5 min  
 364 epoch B) match average 5 min epoch

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

366

367 **\*\*\*Insert Table 3 Here\*\*\***

368

369 Intra-group analysis between AA and BA groups revealed differences (moderate to large Cohen's  $d$  effect sizes)  
 370 between groups in multiple physical measures during: soccer match-play, field testing and measures of both  $VO_2$   
 371 kinetics and  $VO_{2max}$  (Table 4a & 4b). With regards to physical measures during soccer-play, only peak 5 min HSR  
 372 was shown to be 'unclear' between groups (according to Hopkins' (2000) classifications), despite a moderate  
 373 effect size. With respect to laboratory based measures only  $VO_{2max}$  was shown to be significantly larger in the AA  
 374 group, however, the  $\tau$  for pulmonary oxygen uptake kinetics during the transition to moderate intensity exercise  
 375 was faster in the AA group, revealing a large effect size and 'likely positive' inference between groups.

376

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

378

### 379 *Discussion*

380 The main finding of the present study was that there was a significant inverse relationship between the time  
 381 constant ( $\tau$ ) for oxygen uptake kinetics during the transition from unloaded - moderate intensity exercise and  
 382 the amount of high intensity activities performed during soccer match-play as well as performance in the Yo-Yo  
 383 IR1. Furthermore, analysis of 5 min epoch match averages revealed significant inverse relationships between  
 384 unloaded – moderate  $\tau$  and relative HSR. Finally, results from the intra group analysis revealed that players who  
 385 performed above average in the Yo-Yo IR1 test demonstrated superior performance in both laboratory tests  
 386 (unloaded – moderate  $\tau$  and  $VO_{2max}$ ) and physical performance during soccer match-play (Table 4a & 4b).

387

388 To the authors' knowledge this is the first study to examine the impact of measures of  $VO_2$  kinetics, along with  
 389 measures of  $VO_{2max}$ , upon variables of physical performance obtained during soccer match-play, in a group of  
 390 highly trained youth soccer players. As a result, the present study extends and improves upon existing research  
 391 via examining the relationship between  $\tau$ , along with  $VO_{2max}$ , on measures of physical soccer performance in a  
 392 group of highly trained youth soccer players, during both a standardised test (Yo-Yo IR1) and during soccer

393 match-play, using GPS technology. Consequently, this study attempted to adopt a more ecologically valid  
394 approach to evaluating physical soccer performance in relation to measures of  $VO_2$  kinetics. This was achieved  
395 by assessing players' physical performance during soccer match-play, rather than the sole use of a surrogate  
396 indicator of physical soccer performance (e.g. Yo-Yo IR1). Using this innovative approach, present results have  
397 revealed that measures of high intensity activity, obtained during soccer match-play are inversely related to *tau*,  
398 during an unloaded to moderate transition. This supports previous work in both adults and adolescent populations.  
399 Firstly, Rampinini et al. (2010) demonstrated that professional adult soccer players demonstrated a faster *tau*,  
400 (from unloaded to moderate transitions) when compared to amateur soccer players ( $27.2 \pm 3.3$  vs.  $32.3 \pm 5.7$  s).  
401 Secondly, soccer trained male adolescents have been shown to present faster  $VO_2$  kinetics (from unloaded to  
402 moderate transitions) when compared to untrained but recreationally active participants (*tau*:  $22.3 \pm 7.2$  vs.  $29.8$   
403  $\pm 8.4$  s) (Marwood et al., 2010). A finding which is also evident within female adolescent soccer players, when  
404 compared to untrained but recreationally active participants (*tau*:  $26.3 \pm 6.9$  vs.  $35.1 \pm 11.5$  s) (Unnithan et al.,  
405 2015). Current findings, however, expand upon previous research by highlighting the impact of superior  $VO_2$   
406 kinetics upon key measures of physical soccer performance (e.g. HSR activity), during match-play and within a  
407 group of highly trained youth soccer players. Consequently, as levels of high intensity activity have been shown  
408 to be a distinguishing factor of superior soccer performance (Mohr, Krstrup & Bangsbo 2003), an improved  
409 ability to accommodate the necessary energy demands, during soccer match-play, via superior  $VO_2$  kinetics and  
410 utilisation of aerobic pathways may result in a greater accumulation, frequency and maintenance of high intensity  
411 activity.

412

413 Within the assessment of players' physical performance during soccer match-play, a secondary aim was to assess  
414 the impact of  $VO_2$  kinetics on players' physical performance during the peak 5 min epoch, post-peak 5 min epoch  
415 and the match average 5 min epochs. Results demonstrate that while measures of  $VO_2$  kinetics, during an unloaded  
416 – moderate and moderate – severe transition, have little influence upon the amount of high intensity activity  
417 performed over a short period of time (peak 5 min) or in the subsequent 5 min period (post-peak 5 min), measures  
418 of unloaded-moderate *tau* were significantly related to 5 min epoch match averages for measures of HSR, with a  
419 faster unloaded – moderate *tau* equating to a greater 5 min epoch match average for HSR. Thus, there is evidence  
420 to suggest that measures of  $VO_2$  kinetics, particularly unloaded - moderate *tau*, may have a significant impact  
421 upon the maintenance and the ability to sustain levels of high intensity activity over a prolonged period of time

422 (20 - 40 min), during competitive soccer match-play. This is in line with Dupont et al. (2005), who reported a  
423 significant relationship between the phase II  $\tau$ , during a low to moderate transition, and the percentage  
424 decrement in speed during 15 repeated 40 m maximal sprints, with 25 s of active recovery. Together, these results  
425 demonstrate that when numerous bouts of repeated high intensity activity are required, superior  $VO_2$  kinetics are  
426 potentially advantageous to performance via a greater tolerance to mechanisms of fatigue (Buchheit, Abiss, Peiffer  
427 & Laursen, 2012; Dupont et al., 2005). However, the exercise prescribed in the study by Dupont et al. (2005)  
428 greatly exceeds the work that would be experienced during an intense 5 min period of competitive soccer match-  
429 play. Rather, the volume of work prescribed by Dupont et al. (2005) is indicative of the amount of work performed  
430 during a prolonged period of competitive soccer match-play. Nevertheless, current findings suggest that, while  
431 measures of  $VO_2$  kinetics, during an unloaded to moderate transition, may not have an impact upon the high  
432 intensity activity over a short period of time (5 min) during competitive soccer match-play, they do have an  
433 increasing influence over a prolonged period of time. This suggests that superior  $VO_2$  kinetics preserve and help  
434 to maintain intermittent high intensity activity during sustained periods of soccer match-play, a finding which  
435 may be linked to the enhanced ability to activate the more sustainable aerobic energy sources.

436

437 While the present results provide some evidence for the relationship between physical measures associated with  
438 superior soccer performance and  $VO_2$  kinetics, the complex physiology involved during high-intensity  
439 intermittent exercise should be acknowledged. As a result research in this area has produced equivocal results,  
440 with some studies finding little or no relationship between  $VO_2$  kinetics and intermittent exercise performance  
441 (Buchheit, Hader & Mendez-Villanueva, 2012; Christensen et al., 2011; Wells et al., 2012) and other studies  
442 demonstrating significant associations between superior  $VO_2$  kinetics and intermittent exercise capacity (Dupont  
443 et al., 2005; Rampinini et al., 2009; Rampinini et al., 2010). Performance during high-intensity intermittent  
444 exercise, like that which is experienced during soccer match-play, is a product of complex interactions between  
445 metabolic, cardiorespiratory and cardiovascular issues. Indeed, factors such as transportation of ions, metabolite  
446 accumulation, muscle excitability and muscle oxygenation (Girard, Mendez-Villanueva & Bishop, 2011) among  
447 numerous other factors will impact upon the presence of fatigue, and therefore the level of physical performance  
448 during soccer match-play (Bangsbo et al., 2006).

449



450 Consequently, one variable (e.g.  $\tau$  or  $VO_{2\max}$ ) will not, on its own, predict players' intermittent exercise capacity,  
451 as is evidenced by the correlational statistics provided within the present study. Furthermore, the finding that the  
452 AA Yo-Yo group performed significantly more HSR and VHSR than the BA group, despite there being no  
453 significant difference in measures of  $\tau$ , supports the fact that performance during high-intensity intermittent  
454 exercise is multifaceted. Nevertheless, the current results provide an indication to the contribution of the energy  
455 systems during youth soccer match-play, demonstrating that a faster  $\tau$ , during an unloaded to moderate  
456 transition, was associated to the accumulation, frequency and maintenance of high intensity activity during soccer  
457 match-play. Additionally, current results reinforce the adoption of the Yo-Yo IR1 test as an appropriate test for  
458 assessing sport-specific fitness levels in highly trained youth soccer players.

459  
460 Therefore, methods of training which are capable of speeding up  $\tau$ , should improve the accumulation, frequency  
461 and maintenance of high intensity activity during soccer match-play, in highly trained youth soccer players.  
462 Indeed, high intensity conditioning drills or the use of game-based training drills (e.g. small sided games), which  
463 are designed to provide sustained periods (3 - 4min) at an intensity  $>85\%$   $HR_{\max}$ , at a work to rest ratio of 2:1,  
464 may be incorporated as a stimulus to enhance players' aerobic capacity and subsequently improve measures of  
465  $VO_2$  kinetics. Similarly, the use of supra-maximal repeated sprint drills or drills which require a player to work  
466 above their maximal aerobic speed for shorter intervals may be also utilised as a conditioning method for  
467 improving players'  $VO_2$  kinetics (Buchheit & Laursen, 2013).

468  
469 There were no statistically significant relationships between measures of  $VO_2$  kinetics ( $\tau$ ) during the moderate  
470 to severe transitions and any of measures associated with physical soccer performance. Current findings are  
471 supported by those of Nyberg et al. (2016), who reported no change in measures of  $VO_2$  kinetics during a moderate  
472 (10 km/h) to severe (16 km/h) transition in highly trained adult soccer players, following a period of additional  
473 speed endurance training. This was despite significant improvements in Yo-Yo IR1 performance ( $11.6 \pm 6.4\%$ )  
474 and pulmonary  $VO_2$  kinetics during an unloaded to moderate transition ( $11.4 \pm 16.5\%$ ) (Nyberg et al., 2016).

475  
476 In addition, the current results show a large standard deviation is apparent for measures of  $\tau$  during the moderate  
477 - severe transition, these large variations in  $\tau$  may be a result of the intensity prescribed for severe exercise  
478 ( $60\%\Delta$ ). The prescribed intensity of  $60\%\Delta$ , despite being a relative intensity, is likely to be in the proximity of  
479 critical speed (Burnley & Jones, 2007; Ozyener, Rossiter, Ward & Whipp, 2001), resulting in some individuals

480 being above their critical speed and some being below. As a result, this may have elicited different physiological  
481 responses across the current sample. The times recorded, however, for time to exhaustion during the severe  
482 intensity ( $551.6 \pm 167.5$  s) provide support that all players were performing at an intensity above their critical  
483 speed. Nevertheless, the prescribed intensity may have resulted in some individuals not being able to maintain  
484 their performance for a satisfactory amount of time, thus affecting the 'fit' of the  $VO_2$  response. As noted by  
485 Ozyener et al. (2001) the  $VO_2$  kinetics during dynamic muscular exercise are clearly influenced by the exercise  
486 intensity. Research also suggests there is a reduced  $VO_2$  amplitude in the slow component when running compared  
487 to cycling exercise (Carter et al., 2000; Jones & McConnell, 1999). Furthermore, the breath-to-breath noise has  
488 been shown to be large in child populations (Potter, Childs, Houghton & Armstrong, 1998) while the amplitude  
489 of the  $VO_2$  slow component has been shown to be small in child populations (Williams et al., 2001). This can  
490 result in low signal to noise properties within the  $VO_2$  profiles and impact upon the fitting of the moderate - severe  
491 transition, making it difficult to reliably identify the non-steady state 'phase' of the  $VO_2$  response during this  
492 transition (Armstrong & Barker, 2009). To date, there is limited knowledge as to whether or not trained individuals  
493 actually present faster  $VO_2$  kinetics during work-work transitions and, therefore, the applicability of  $VO_2$  kinetics  
494 profiles obtained during a moderate to severe transition and their relationship to physical soccer performance  
495 requires further research. Although, initial results from the current study and that of Nyberg et al. (2016) would  
496 seem to indicate that the  $VO_2$  kinetics profile obtained from a moderate to severe transition is unrelated and not  
497 influenced by the high-intensity intermittent exercise that is experienced during soccer match-play.

498

499 Previous research that has examined the relationship between  $VO_2$  kinetics and physical measures associated with  
500 soccer match-play has failed to provide physical data from performance during competitive soccer match-play.  
501 The addition of such information will improve the ecological validity and application of measures obtained from  
502 both laboratory and field tests to team sports performance. It is understood, however, that reasonable levels of  
503 game to game variation exist within soccer match-play (Gregson et al., 2010). Indeed, Gregson et al. (2010)  
504 reported high levels of variance for HSR ( $CV = 16.2 \pm 6.2\%$ ) during elite adult competitive football when  
505 analysing players' physical performance across two seasons. Information regarding the variance in physical  
506 performance, for youth soccer players is lacking, however, analysis of the variance across the three matches  
507 employed within the current study revealed typical errors of 4.3 m/min for TD, 316 m & 24 efforts in the HSR  
508 threshold and 75 m & 5 efforts in the VHSR threshold. While the values presented are substantial, when applied

509 in relation to the data reported for the AA and BA groups, within the current study, the difference between groups  
510 is in excess of the typical errors presented.

511

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

518

519 Finally, the potential impact of growth and maturation should not be ignored when assessing youth soccer players.

520 In the present study, however, the effects of growth and maturation upon the fitness components measured was  
521 equivocal. Indeed, no relationships between maturation status, measured via Tanner Stage and Maturity Offset,  
522 were found between measures of  $\dot{V}O_2$  kinetics and measures associated with physical performance during soccer  
523 match-play. Although, the limitations of the adopted methods used to assess growth and maturation do need to be  
524 acknowledged. Firstly, the Tanner stage method of maturation does not provide information on the point at which  
525 a player entered a particular stage of maturation or how long an individual has been in a particular stage of  
526 maturation (Malina et al., 2012). Secondly, the accuracy of the predictive equation used to determine the maturity  
527 off-set has been shown to decrease the further the individual is away from the period of peak height velocity  
528 (Malina, Cumming, Morano, Barron & Miller, 2005). Nevertheless, the impact of growth and maturation within  
529 the current sample, particularly during the intra-group analysis, was negligible. Furthermore, partial correlations  
530 were employed throughout to control for any possible influence of growth and maturation. Despite these  
531 limitations the current study extends and improves upon the existing research by examining distinct measures of  
532 cardio-respiratory fitness in relation to measures of physical performance obtained during soccer match-play in  
533 elite youth soccer players.

534

### 535 **Conclusion**

536 The results from this study demonstrate that players with a superior ability to activate aerobic energy pathways at  
537 the onset of exercise, evidenced by a faster *tau* during transitions from low to moderate intensity exercise, tend to  
538 perform better in Yo-Yo IR1 and perform a greater amount of relative HSR during soccer match-play. Hence, the

539 accumulation, maintenance and frequency of high intensity activity during competitive soccer match-play, in  
 540 highly trained youth soccer players, are associated with a faster *tau* during an unloaded to moderate exercise  
 541 transition but unrelated to *tau* during a moderate – severe exercise transition. This study demonstrates that  
 542 measures obtained from  $\text{VO}_2$  kinetics testing protocols may be of benefit when assessing youth players' physical  
 543 performance during soccer match-play and could therefore be used as a measure to distinguish those of superior  
 544 physical performance. Based on these findings, the physiological capacity to transition rapidly between  
 545 workloads, particularly from low – moderate intensities, is a potential determinant of superior physical  
 546 performance (specifically high intensity activities), during soccer match-play, in highly trained youth soccer  
 547 players.

548

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