Influence of Cardio-Respiratory Fitness on Physical Performance in Elite Youth Soccer

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Abstract

The purpose of this study was to assess the relationship between: Peak oxygen uptake (VO_{2max}) and running economy (RE) with physical measures associated with elite youth soccer performance obtained during soccer match-play. Seventeen highly trained youth soccer players (age: 13.3±0.4y) volunteered to participate. Initially player's ventilatory threshold (VT) and VO_{2max} was established using a treadmill protocol. On the subsequent visit, players ran for 4 min, at three different speeds (8km/h, 80%VT and 95%VT). Physical soccer-based performance was assessed using a maximal Yo-Yo IR1 and via Global positioning systems (GPS) derived variables obtained during three, 2x20min, 11 v 11 soccer matches. Partial correlations revealed significant relationships between relative VO_{2max} and measures of physical soccer performance (r = 0.54–0.88). Moreover, measures of ventilatory equivalent (V_EVO_2), a determinant of RE, at all sub-maximal exercise intensities were inversely related to the volume (m) and percentage (%) of very high intensity activities. Current findings emphasise the need for high levels of cardio-respiratory fitness in high level youth soccer players, with superior levels of fitness being associated with a greater amount of high and very high intensity activity during soccer match-play.

Keywords: Aerobic Capacity; Running Economy; Youth Soccer; Team Sports; Respiratory Fatigue

Abbrevations: RE: Running Economy; VT: Ventilatory Threshold; GPS: Global Positioning Systems; RER: Respiratory Exchange Ratio; GET: Gaseous Exchange Threshold

Introduction

Soccer is described as a high-intensity intermittent sport, with elite players demonstrating a superior ability to perform high-intensity activities during competitive match-play in both adult [1] and youth [2] soccer. During match-play, however, low intensity activities account for the majority of an individual's physical performance, at all levels of competition [3,4]. As a result, the aerobic energy system is the predominant source of energy expenditure during soccer match-play, accounting for more than 90% of the total energy demand [3]. Furthermore, research suggests that youth populations are better equipped to use oxidative energy pathways, when compared to adult populations, resulting in a greater utilisation of aerobic energy pathways for the same relative exercise intensity and reduced level of metabolic acidosis [5,6]. Consequently, determinants of cardio-respiratory (aerobic) fitness may have a significant impact upon youth players' physical performance during soccer match-play and, in particular, their ability to perform repeated bouts of high intensity activities. Superior levels of maximum oxygen consumption (VO_{2max}) will, theoretically, enable players to work at a higher intensity during soccer match-play, for a lower relative energy cost than those with inferior levels of VO_{2max} [1]. Furthermore, soccer-specific endurance capacity has been shown to be an essential characteristic for youth players aiming to progress to elite adult status [7,8]. Despite this, the impact of enhanced aerobic capacity(VO_{2max}) on physical soccer performance has produced equivocal results. With some studies reporting positive relationships between VO_{2max} and physical performance measures associated with soccer match-play [9], while others have reported no relationship between VO_{2max} and measures of physical performance [10]. Rebelo et al. [10] reported that the high intensity running performed during a competitive match, in adult soccer was closely related to a player's VO_{2max} (r = 0.81). Despite the equivocal nature of the relationship between VO_{2max} and markers of match-play, the attainment of

measures of physical performance in situ (during match-play) are lacking. Such measures will enhance the ecological validity and application of measures obtained from both laboratory and field tests, when used to assess team sports performance. Thus, aiding in the assessment of the relationship between cardio-respiratory fitness and team sports performance, with further implications for training practices as well as talent identification and development.

Large components of competitive soccer match-play are comprised of low intensity activity [3], as a result, superior levels of running economy (RE) may result in the preservation of energy during periods of low-intensity exercise. Work by Ziogas et al. [11] revealed that players who competed in a higher division had a superior RE when running at 12 km/h⁻¹ (Division A = 75.8%, Division B = 78.7%, Division C = 80.5% VO2max). This demonstrates that measures of RE (expressed as a percentage of VO2max) may be able to discriminate between playing level, but provides no indication to the extent to which RE may impact upon physical performance during soccer match-play. Moreover, Stroyer et al. [4] assessed the RE and the activity patterns of young soccer players during match-play, however the relationship between the two measures was not reported. As a result, the contribution that RE and determinants of RE may play with regard to effective soccer-match play, particularly in youth populations, where there is an increased reliance upon aerobic energy production [5,12], requires investigating. Furthermore, due to the intensified [13], exhaustive and intermittent [1,3] nature of soccer, other determinants of RE may also provide an indication toward an individual's ability to perform high-intensity activities during soccer match-play. Di Paco et al. [14] demonstrated an improved ventilatory efficiency for a given exercise intensity in soccer players of a superior fitness level. Consequently, the purpose of this study was to determine the relationship between: VO2max, RE and determinants of RE, and physical measures associated with elite youth soccer performance during soccer match-play within a group of highly trained youth soccer players. It was hypothesized that superior measures of VO2max, RE and parameters of RE would be significantly correlated with physical performance measures during elite youth soccer match-play.

Methods

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 Soccer Academy. Prior to the commencement of the study, all players completed medical health questionnaires and training history questionnaires. Table 1 illustrates all anthropometric and screening measures. Maturity status was quantified using self-assessment, Tanner Stage method and maturity offset [15]. Players and their parents were informed about all procedures and requirements involved in the study before providing written

informed consent and assent from parents and participants, respectively. Ethical approval was granted from the local university ethics committee prior to the commencement of the study. Data collection was conducted over a three-week period at the beginning of a competitive season (pre-season). During this period, anthropometric measurements as well as laboratory and field tests were conducted. The players visited the laboratory on 2 separate occasions, they then performed a field test and were involved in 3 sterile (same playing surface, pitch dimensions and including the same composition of players in the same positions) 11 v 11 matches. Goal keepers were excluded from the analysis due to the incomparable match demands with outfield players. Furthermore, while two teams of 10 outfield players equates to 20 potential participants, 3 of the players (despite taking part in the training matches) chose not to participate in the study, thus leaving a sample of 17 participants. During the first visit, players performed an incremental, ramp treadmill protocol for the assessment of players' gaseous exchange threshold (GET) and VO_{2max}. Players returned to the laboratory for a second time, following a minimum of 24 hours of recovery. On the second visit, players were required to run for 4min, at progressive sub-maximal speeds (8km/h, 80%GET and 95%GET), with 2 min passive recovery between speed increments. Players then completed the field test and 3 sterile 11 v 11 matches over the following 2 weeks with a minimum of 48 hours between each test. All laboratory and field testing were completed at the same time of day (± 2 hours), with room temperature, humidity and pressure corresponding to 20.5 ± 1.5ºC, 61.0 ± 1.4% and 1016 ± 3mmHg respectively, for laboratory testing.

Table 1: Anthropometric and screening measures.

Variable	Mean ± Standard Deviation	95% Confidence Intervals
Age (y)	13.3 ± 0.4	13.1 - 13.5
Stature (m)	1.59 ± 0.11	1.54 - 1.64
Body Mass (kg)	48.9 ± 10.1	43.9 - 53.9
Maturity Offset (y)	-0.8 ± 0.9	-1.2 to - 0.3
Σ 4 Skinfolds (mm)	30.7 ± 5.1	28.3 - 33.1
Tanner Stage	3 ± 1	2 - 3
Training Years (y)	4.4 ± 2.1	3.4 - 5.3
Training Hours (hrs.p.week)	12.4 ± 2.3	11.3 - 13.5

Upon arrival to the laboratory and following the necessary screening procedures, 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 Meta Max 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 10min warm up and a full

description of the test and safety procedures, participants began to run at a speed of 8km/h at a 1% incline [16] on a motorised treadmill (HP Cosmos, Pulsar, Sportgerate GmbH, Nussdorf, Germany). The speed of the treadmill was increased by 1km/h every two minutes, this continued until participants reached 90% of their age predicted heart rate max (207-(0.7 x age)) [17]. 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 VO_{2max}. This method has been successfully used before to elicit VO_{2max} during treadmill running in young athletes [18]. Rolling 15 sec averages were calculated for the final minute of the test to verify if a plateau was present, with the highest 15 sec average during the test being regarded as VO_{2max} [19]. It is well documented that children can exercise to exhaustion without exhibiting a VO_2 plateau [20]. Nevertheless, 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 VO_2 despite an increasing speed ($< 2mL \cdot kg^{-1} \cdot min^{-1}$; 10) 3) heart rate ±10 beats/min of age predicted maximal heart rate [20]. The VO_{2max} protocol resulted in 100% percent of the participants reaching an RER value of greater than 1.00 and a heart rate value within ±10beats/min of age predicted maximal heart rate, while 88% of the participants presented a plateau in VO_2 despite an increase in speed. As all players did fulfil two of the stated criteria, the term VO_{2max} was preferred [21].

The gaseous exchange threshold (GET) was identified using the V-slope method (V_E (ordinate), VO_2 (abscissa)). Two regression lines were created based upon the relationship between VCO_2 and VO_2. The intercept point between the two regression lines was then visually identified, with the VO_2 value at the intercept (GETS) being extrapolated to the abscissa [22]. To identify the speed at GET, a regression equation was formulated for VO_2 and running velocity, for each individual. The individual's VO_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 [23]. 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 was approached to verify the GET. Following this test, running velocities corresponding to 80% GET and 95% GET were calculated for the assessment of running economy. On the subsequent visit to the laboratory, and following a minimum of 24 hours recovery, participants' RE was assessed at three progressive sub-maximal intensities (one absolute: 8km/h and two relatives: 80% GET and 95% GET exercise intensities), with 2 min passive recovery between each intensity. Prior to testing, participants were fitted with a Polar Heart rate monitor and face-mask, which was connected to a pre-calibrated online gas analysis system. Following a standardised 10min warm-up

and a full description of the test procedures, participants began to run at the lowest exercise intensity (either 8km/hour the running velocity equivalent to 80% GET), with the gradient of the treadmill set at 1% [16]. Participants ran at this speed for 4 min, ensuring that a steady state was maintained for the final minute [21]. A 2min passive recovery was then permitted, in which participants' heart rate recovered to pre-exercise levels. Pilot testing demonstrated that a 2min passive recovery was shown to provide sufficient time for players to recover to resting heart rate levels, ensuring there were no ensuing effects on the subsequent exercise bouts. During this recovery period, the treadmill speed was increased to the next progressive speed (higher intensity of 8km/h^{-1} or 80% GET). Again, participants exercised at this speed for 4min, attaining a steady state, before undertaking a further 2min recovery. Following the final 2min of passive recovery, participants completed another 4min period of sub-maximal running at the highest intensity (95% GET).

Extraction of the appropriate measures for assessing RE included applying rolling 15sec averages for the final minute of each sub-maximal exercise intensity to ensure that a steady state had been attained. It has been shown that male youth populations will attain a steady state following 3min of sub-maximal exercise [23]. Current results revealed that all participants (100%) attained a steady state ($< 2mL \bullet kg^{-1} \bullet min^{-1}$ (10), in the final minute of exercise) for each sub-maximal exercise intensity. Following the identification of a steady state, RE was defined as the average VO2 during the final minute of each exercise bout [21]. Relative oxygen consumption (VO2) was obtained for each exercise intensity as well as determinants of RE: minute ventilation (VE) and ventilatory equivalent (VEVO2). For the Yo-Yo IR1 test, cones were placed 20m apart, with a 5m recovery zone marked out at one end. The Yo-Yo IR1 test requires participants to run 2 x 20m 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 maximal 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. All players had previous experience of completing the Yo-Yo IR1 test and were therefore familiarised to the testing. During the test, players were allowed to consume fluids ad libitum. Previous evidence supports the use of the Yo-Yo IR1 test as a valid measure of soccer-specific fitness, particularly within youth populations [24].

For the assessment of participants' performance during soccer match-play, three separate, sterile (controlled, replicable and include the same composition of players in the same positions) 11 v 11 matches were conducted and analysed using 10Hz GPS (Catapult, Melbourne, Australia) and Polar Heart rate monitors. Each match was conducted on the same third generation outdoor artificial pitch with the same pitch

dimensions utilised within competitive match-play within this population (90 x 50m) and at the same time of day. Matches were comprised of 2 x 20min halves with a 5min 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 for all matches. Matches were performed on three separate occasions with a minimum of 24hrs between matches.

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 20min half and into successive 5min epochs (e.g. 0-5min, 1-6min, 2-7min, 3-8min, etc), to establish and quantify the peak 5min epoch, the subsequent 5 min epoch to the peak 5 min epoch and the mean of the cumulative 5min epochs throughout the match. These were then averaged over the 3 sterile matches. Previous research has used discrete 5min epochs (0-5min, 5-10min, etc.) to identify the peak 5min interval during soccer match-play [25]. However, the adoption of such criteria may result in missing the true peak 5min epoch, as this may occur between the pre-determined, discrete 5min epochs. Consequently, matches were analysed using successive 5min epochs (0-5min, 1-6min, 2-7min, etc.) for the identification of the most intense 5min epoch. Information recorded included total distance (TD), metres per min (m/min), relative high speed running distance metres (HSR), relative high speed efforts (HSReff), and relative very high speed running distance metres (VHSR), relative very high speed efforts (VHSReff) and relative sprint distance metres (S). 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. Maximal velocity was defined as the maximal velocity obtained during a 20m sprint from a standing start and obtained from the respective GPS devices which the player would wear during the competitive and sterile soccer matches.

A Shapiro Wilks test found the data to be normally distributed; therefore parametric statistical calculations were applied. Partial correlations, controlling for maturation, were performed on the whole sample to assess the relationship between measures of cardio-respiratory fitness and physical soccer-based measures. 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 [26] (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).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

Partial correlations revealed significant relationships between VO_{2max} (mL•kg^{-1}•min^{-1}) and measures associated with physical soccer performance (r = 0.54–0.88), while measures of velocity at GET were only shown to be related to total distance (r = 0.51, P <0.05) and VHSR (r = 0.51, P <0.05). Only %VO_{2max} at an absolute sub-maximal intensity of 8km/h revealed significant inverse correlations with TD (r = -0.58, P <0.05) and the volume (r = -0.65, P <0.05) and percentage of HSR during soccer match-play (r = -0.61, P <0.05) as well as the number of HSR (r = -0.58, P <0.05) and VHSR (r = -0.56, P <0.05) efforts. With regards to measures and determinants of RE, only V_EVO_2 at all sub-maximal exercise intensities were inversely related to the volume (m) and percentage (%) of VHSR performed during the sterile soccer matches as well as the number of VHSR efforts (Table 2). Partial correlations between GPS derived variables, obtained during players' most intense 5min period of match-play (i.e. peak 5min epochs) and relative VO_{2max} revealed no relationships, while velocity at GET was shown to be significantly related to measures of high intensity activity during players' peak 5min epochs. However, partial correlations with the same GPS derived variables and relative VO_{2max} (mL•kg^{-1}•min^{-1}) for the average 5min epochs (the mean average of the cumulative 5min epoch throughout match-play) were all significantly related. With regards to measures of running economy, again, only V_EVO_2 at all sub-maximal exercise intensities were inversely related to the volume (m), percentage (%) and efforts for VHSR, within the average 5min epochs (Table 3).

Table 2: Partial correlations between GPS derived measures of soccer match-play and measures of cardio-respiratory fitness (r values).

	Measures of Physical Soccer Performance							
	Max Yo-Yo	TD (m)	HSR (m)	VHSR (m)	HSR (%)	VHSR (%)	HSR efforts	VHSR efforts
Yo-Yo IR1	-	*0.63	*0.64	*0.59	*0.61	*0.57	*0.60	*0.63
VO_{2max} (mL•kg^{-1}•min^1)	*0.88	*0.59	*0.73	*0.57	*0.70	*0.54	*0.74	*0.62
Velocity at GET (km/h)	0.48	*0.51	0.39	*0.51	0.33	0.49	0.28	0.44
V_EVO_2 @ 8km/h	-0.49	-0.39	-0.38	*-0.69	-0.34	*-0.66	-0.33	*-0.67
RER @ 8km/h	-0.36	*-0.56	-0.18	-0.48	-0.42	-0.20	-0.07	-0.41
%HR_{max} @8km/h	0.20	-0.19	-0.27	0.02	-0.24	0.03	-0.23	0.00

%VO$_{2max}$ @ 8km/h	-0.42	*-0.58	*-0.65	-0.47	*-0.61	-0.47	*-0.58	*-0.56
V$_E$VO$_2$ @ 80%GET	-0.22	-0.02	-0.32	*-0.64	-0.36	*-0.64	-0.35	*-0.66
RER @ 80%GET	0.25	-0.02	-0.14	-0.33	-0.15	-0.29	-0.10	-0.26
%HR$_{max}$ @80%GET	0.25	-0.04	0.01	0.18	0.04	0.19	-0.05	0.15
%VO$_{2max}$ @ 80%GET	-0.25	-0.39	-0.38	-0.07	-0.36	-0.06	-0.37	-0.18
V$_E$VO$_2$ @ 95%GET	-0.50	-0.24	-0.44	*-0.62	-0.46	*-0.61	-0.44	*-0.67
RER @ 95%GET	-0.13	-0.20	-0.13	-0.20	-0.11	-0.14	-0.08	-0.14
%HR$_{max}$ @95%GET	0.07	0.06	0.09	0.27	0.11	0.29	0.02	0.20
%VO$_{2max}$ @ 95%GET	-0.30	-0.49	-0.46	-0.06	-0.42	-0.03	-0.49	-0.15

Note: VO$_{2max}$ = Maximal oxygen consumption; GET = Gaseous exchange threshold; V$_E$VO$_2$ = Ventilatory equivalent; RER = Respiratory exchange ratio; %HR$_{max}$ = percentage of maximum heart rate; TD = Total Distance; HSR = High speed running; VHSR; Very high-speed running. Partial correlations were controlled for using self-assessed Tanner Stage values, * = significant correlation (P< 0.05).

Table 3: Partial correlations between GPS derived measures of soccer match-play, during a peak 5 min epoch and match average 5min epoch, and measures of cardio-respiratory fitness (r values).

	Peak 5min epoch					Match averages for 5min epochs				
	TD (m)	HSR (m)	VHSR (m)	HSR efforts	VHSR efforts	TD (m)	HSR (m)	VHSR (m)	HSR efforts	VHSR efforts
Yo-Yo IR1	0.22	0.41	*0.53	0.45	*0.56	*0.59	*0.50	*0.53	0.46	*0.51
VO$_{2max}$ (mL·kg^{-1}·min^{-1})	0.19	0.29	0.36	0.29	0.36	*0.60	*0.56	*0.55	*0.51	*0.53
Velocity at GET	0.25	*0.58	*0.55	*0.60	*0.57	0.38	0.29	0.35	0.26	0.34
V$_E$VO$_2$ @ 8km/h	-0.38	-0.48	-0.38	*-0.62	-0.48	-0.26	*-0.51	*-0.66	*-0.51	*-0.66
RER @ 8km/h	*-0.73	*-0.62	*-0.53	*-0.59	*-0.53	*-0.55	*-0.56	*-0.64	*-0.50	*-0.63
%HR$_{max}$ @8km/h	-0.11	0.11	0.14	0.20	0.17	-0.25	-0.04	0.12	-0.04	0.13
%VO$_{2max}$ @ 8km/h	-0.24	*-0.57	-0.29	*-0.54	-0.29	*-0.52	*-0.61	-0.47	*-0.60	-0.45
V$_E$VO$_2$ @ 80%GET	-0.23	-0.27	-0.08	-0.43	-0.19	0.02	-0.48	*-0.61	-0.48	*-0.61
RER @ 80%GET	-0.44	-0.04	0.08	-0.09	0.03	-0.07	-0.29	-0.35	-0.31	-0.36
%HR$_{max}$ @80%GET	0.05	0.31	0.32	0.39	0.35	-0.05	0.02	0.19	0.01	0.20
%VO$_{2max}$ @ 80%GET	-0.07	0.07	0.12	0.05	0.09	-0.32	-0.32	-0.18	-0.39	-0.18
V$_E$VO$_2$ @ 95%GET	-0.26	-0.35	-0.12	*-0.51	-0.24	-0.16	*-0.52	*-0.61	*-0.53	*-0.60
RER @ 95%GET	-0.31	0.10	0.06	0.05	0.00	-0.23	-0.14	-0.21	-0.17	-0.20
%HR$_{max}$ @95%GET	0.20	*0.50	0.40	0.45	0.34	0.07	0.17	0.25	0.14	0.25
%VO$_{2max}$ @ 95%GET	-0.09	0.16	0.11	0.21	0.13	-0.46	-0.27	-0.07	-0.28	-0.06

Note: VO$_{2max}$ =Peak oxygen consumption; GET =Gaseous exchange threshold; V$_E$VO$_2$ =Ventilatory equivalent; RER =Respiratory exchange ratio; %HR$_{max}$ =percentage of maximum heart rate; TD =Total Distance; HSR =High speed running; VHSR; Very high-speed running. Partial correlations were controlled for using self-assessed Tanner Stage values, * = significant correlation (P< 0.05).

Discussion

The main findings of this study were 1) measures of relative VO$_{2max}$ were significantly related to multiple measures of physical performance that are associated with superior soccer match-play; 2) RE (expressed as % VO$_{2max}$) at an absolute intensity of 8 km/h was significantly related to measures of high intensity activities performed during youth soccer match-play; and 3) while traditional measures of RE (%VO$_{2max}$), at relative intensities, were unrelated to measures of physical performance, a determinant of RE (V$_E$VO$_2$), at all sub-maximal treadmill intensities (absolute and relative) was inversely related to measures of VHSR (metres, percentage and efforts), but not HSR, during competitive soccer match-play. To the authors' knowledge, this study is the first to assess the relationship between multiple measures of cardio-respiratory fitness in relation to physical soccer performance outcome measures, obtained during competitive soccer match-play, in a group of highly trained youth players. Current findings support research that states measures of relative VO$_{2max}$ (ml.kg^{-1}.min^{-1}) and Yo-Yo IR1 performance are related to measures of physical performance during soccer match-play [27]. Present results found that VO$_{2max}$ and measures of HSR (HSR metres: r = 0.73, P< 0.05; HSR%: r = 0.70, P< 0.05 and HSR efforts: r = 0.74, P< 0.05) and VHSR (VHSR metres r = 0.57, P< 0.05; VHSR%: r = 0.54, P< 0.05 and VHSR efforts: r = 0.62, P< 0.05), obtained during competitive soccer match-play were significantly related. Indeed, the contribution of aerobic energy supply has been shown to compensate for reductions in the energy supply from anaerobic metabolism during repeated sprints [28]. As a result,

an enhanced ability to utilise oxidative energy pathways during high-intensity intermittent exercise may result in a greater accumulation, maintenance and frequency of high-intensity activities, thus maximising a players opportunity to compete effectively.

Similar to the present study, Krustrup et al. [9] reported significant relationships between measures of relative VO_{2max} and high-intensity distance covered during soccer match-play (r = 0.81), in elite female soccer players. Rebelo et al. [10], however, reported no significant relationships between measures of VO_{2max} and time spent in absolute speed zones during soccer-match play (r =-0.13-0.25; P>0.05). However, it must be noted that Rebelo et al. [10] assessed players' physical performance during soccer match-play using time-motion analysis, one individual at a time and over a variety of games, thus exacerbating the issues of inter-match variability associated with assessing physical soccer performance during soccer match-play [29]. In the current study, all players were assessed simultaneously, using GPS analysis and during sterile soccer matches, in order to account for the complexities of variance involved in assessing physical performance during soccer match-play.

The current results demonstrate that traditional measures of RE (VO2 or $\%VO_{2max}$) when exercising at an absolute intensity (8km/h) are related to measures of physical performance during soccer match-play. However, when RE is measured at a relative (80%GET and 95%GET) exercise intensity, traditional measures of RE are not related to variables associated with superior physical soccer performance during match-play, within a group of highly trained youth soccer players. The use of RE as a measure to assess soccer-specific fitness is rarely adopted, this is probably due to the high-intensity, intermittent characteristics of soccer match-play. Despite this, research has advocated the need to improve soccer players' levels of RE via training [11]. In support of this, the current results demonstrated that a superior RE during an absolute intensity of 8 km/h was significantly related to measures of HSR during soccer match-play. The current findings, however, may be a result of the different internal load which an absolute intensity of 8 km/h equates to for each player, although such a finding may still be relevant as physical performance during competitive match-play does not account for players' relative fitness levels, maturity status or size (e.g. leg length) either. Consequently, the use of absolute sub-maximal intensities may be preferable when utilising traditional measures of RE to distinguish between physical performance during youth soccer match-play. Conversely, when relative exercise intensities (80% and 95% GET) were employed to assess RE, no relationships between traditional measures of RE and physical measures of performance during soccer match-play were evident. When, however, alternative determinants of RE are evaluated with respect to their relationship with physical soccer performance different relationships emerge.

While results from the present study provide little support for relationships between measurements of RE and physical performance during soccer-match-play, a significant inverse relationship between V_EVO_2 and measures associated with physical soccer performance was demonstrated. Work by Franch et al. [13] reported an average decrement of 11 L.min^{-1}, in VE, while exercising at an intensity equivalent to 85% VO_{2max}, following 6 weeks of intensive endurance-based interval training. In addition, these same authors reported that other determinants of running economy such as: stride length, stride frequency, respiratory exchange ratio and muscle fibre distribution were unaltered. As a result, the responsiveness of V_E to high intensity intermittent training, like that which is experienced during soccer, may have a positive impact on physical performance during soccer match-play; with players at a higher level demonstrating an enhanced ventilatory efficiency (V_EVO_2) for a given exercise intensity [14] and therefore increased levels of physical performance during soccer match-play.

There were some limitations associated with this study. Firstly, correlation analyses do not infer causality. The 'third-variable problem' must be considered, as other measured or un-measured variables may affect the results. In an attempt to account for this, partial correlations were employed to control for the effects of maturation. Furthermore, the techniques used to assess maturity status within this study should also be considered. Indeed, the Tanner stage method of estimating maturity status 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. Finally, relative thresholds were used to assess players' physical performance during soccer match-play. While this partly accounts for differences in growth and maturation, future research may look to examine the impact of such relationships when utilising both relative and absolute speed thresholds within the GPS analysis, when evaluating physical performance during soccer match-play. Such research will allow practitioners and researchers to establish the most appropriate methods for quantifying youth players' physical performance in both competition and training.

Practical Implications

The current paper looks to extend and improve upon existing research by providing an insight into the extent to which measures of cardio-respiratory fitness impact upon measures of physical performance during youth soccer match-play. An improved understanding of the extent to which specific measures impact upon physical performance during youth soccer match-play will enable both sports practitioners and coaches to devise and implement training practices which are aligned to performance. Specifically, current results demonstrate that measures of relative VO_2 peak are related to measures of physical performance. Therefore, measures of relative VO_2 peak

may be an appropriate means for assessing and monitoring youth players' physical development and player profiling, thus aiding in the identification of age appropriate training objectives for each player's individual development. Finally, the potential to delay the onset of respiratory muscle fatigue, during high intensity intermittent exercise provides interesting results. A delay in the onset of respiratory muscle fatigue may result in improvements in the amount of activity that can be performed at higher intensities, during soccer match-play. Consequently, sports practitioners may wish to promote the use of inspiratory muscle training as a concurrent training aid to supplement training outcomes.

Conclusion

Results of the present study reinforces evidence that suggests an enhanced VO_{2max} is associated with superior soccer performance, in a group of highly trained youth soccer players, with a superior aerobic capacity allowing for an improved maintenance of high intensity activities during soccer match-play. Strong correlations between VO_{2max} and physical performance during soccer match-play (high intensity activities) emphasises the need for high levels of aerobic capacity in highly trained youth soccer players. Moreover, while no relationships between traditional measures of RE and physical measures associated with soccer performance were evident, results provided potential support towards the implications of ventilatory efficiency (V_EVO_2) and its impact upon very high intensity activities (VHSR metres and efforts) during soccer match-play. However, further research should look to investigate the direct impact of ventilatory efficiency on measures associated with physical soccer performance during competitive match-play.

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