UNIVERSITY OF TECHNOLOGY, SYDNEY

Match running performance and physical fitness in youth soccer players: A longitudinal study

A thesis submitted for the degree

Master of Sport & Exercise Science

January 2015

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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree at the University of Technology Sydney nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me, Ben Michael Simpson. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Signature of Student

4th January 2015

Date

Acknowledgements

The completion of this thesis was made only possible by the support and encouragement of the following people.

The following three gentlemen in their own ways made this achievement possible and realistic for me. Without their continual guidance I am not sure where I would be today, both at professional and personal levels. Professor Aaron Coutts has gone over and above what was definitely required of him, I only wish that I could be as efficient and effective as he is and repay his generosity. Being an off-campus student, proved difficult at times, but Aaron stood by me, helpful by all means along the way! Professor Martin Buchheit, not only the support provided from an educational prospective, but as a friend and someone I look up to everyday, thank you for always believing in me. You know I can never repay what you have provided me and continue to do for me. Thank you. Dr. Alberto Mendez, thank you for firstly giving me the chance to join your team of Physiologists with Aspire football. To this day and beyond I will never stop learning from you, my Spanish inspiration! The above three have guided and assisted me more than what is probably required, I thank them all for their individual help.

I would also like to thank Dr. Hani Al Haddad for his support as a colleague and friend, the coaching staff and each and every player at ASPIRE – Sports Academy that I have had the pleasure of working with.

This research received financial support provided by ASPIRE – Sports Academy.

Preface

This thesis for the degree of Master of Sport and Exercise Science is in the format of ready for submission manuscripts and abides by the 'Procedures for Presentation and Submission of Theses for Higher Degrees – University of Technology, Sydney; Policies and Directions of the University'. All manuscripts included in this thesis are closely related in subject matter and form a cohesive research narrative.

Based on the research design and data collected by the candidate, one paper has been prepared for submission to an international, peer-reviewed journal. This thesis is brought together by an *Introduction*, which provides background information, defines the research problem and the aim of each study. The a *Literature Review* provides an overview of previous knowledge that characterizes match running performance and physical capacities of youth level soccer players, methods to measure the link between match running performance and physical fitness and means to improve those variables.

This manuscript outlines and discusses the individual methodology and the findings of the study. The *General Discussion* chapter provides an interpretation of the collective findings and practical applications from the series of investigations conducted. To finish, a *Conclusion and Practical Implications* chapter summarizes the conclusions from the project. Future research is suggested on the basis of the findings from the studies. The APA reference style has been used throughout the document and the reference list is at the end of the thesis.

ABSTRACT

This study examined whether substantial changes in either maximal sprinting speed (MSS) or maximal aerobic speed ($V_{vam\text{-}Eval}$) are related to changes in match running performance activity during match play in highly-trained young soccer players. A retrospective longitudinal research design was used where physical fitness and match analysis data were collected. Data from 44 players (U13-U18; fullbacks [FB, n=12], centre-backs [CB, n=12], mid-fielders [MD, n=11], wide-midfielders [WM, n=5], strikers [S, n=4]) who had substantial changes in either MSS or $V_{vam\text{-}Eval}$ throughout 2 consecutive testing periods (~3 months) were included in the final analysis. For each player, time-motion analyses were performed using a global positioning system (1-Hz) during 2-10 international level games played within 1-2 months from/to each testing period of interest. Match activity profiles were described using both absolute and relative zones. Absolute match running activities were defined as meters per min ($m \cdot min^{-1}$), low-intensity activities (LIA), high-intensity running (HIR), very high-intensity running (VHIR) and sprint activities (SPRT), where relative match activities were categorized into 5 intensity zones in relation to individual MSS and MAS. Improvements in both MSS and $V_{vam\text{-}Eval}$ were likely associated with either non-substantial or lower magnitude changes in match running performance variables and between playing positions. While in response to using relative thresholds, measures were either unchanged or decreased substantially in response to an increase in MSS and/or MAS. Collectively, the results demonstrate that in match running activities during games do not necessarily match those in physical fitness in highly trained young soccer players. Game tactical and strategic requirements are likely to modulate on-field players' activity patterns independently of players' physical capacities.

Keywords

Developing players

Football

GPS

High-intensity running

High-speed activities

Individual intensity

thresholds

Locomotor function

Low-intensity running

Match analysis

Physical fitness

Time-motion analysis

List of Abbreviations

ASR	anaerobic speed reserve
CB	centre-back
CI	Confidence Interval
cm	centimetres
CMJ	counter movement jump
CV	coefficient of variation
ES	Standardised effect size
FB	full-back
GPS	Global Positioning System
GXT	graded exercise test
HIR	high-intensity running
HR	heart rate
Hz	Hertz
ISAK	International Society for the Advancement of Kinanthropometry
kg	kilograms
km/hr	Kilometers per hour
KMS	kinematic measuring system
LIR	low-intensity running
m	meters
MAS	Maximal aerobic speed
MD	mid fielder
min	minute
MSS	maximal sprinting speed
p	significance
PHV	peak height velocity
PSV	peak strength velocity
PWV	peak weight velocity
r	Pearson's correlation coefficient
RCT	Respiratory compensation threshold
RSA	repeated sprint ability
RSA_{mean}	repeated sprint ability mean
s	seconds
S	striker
S1	speed zone 1
S2	speed zone 2
S3	speed zone 3
S4	speed zone 4
S5	speed zone 5
SD	standard deviation
SPRT	sprinting
TD	total distance covered
U13	Under 13 years of age

U14	Under 14 years of age
U15	Under 15 years of age
U16	Under 16 years of age
U17	Under 17 years of age
U18	Under 18 years of age
UMTT	Universal of Montreal Track Test
VHIA	very high-intensity activities
VHIR	very high-intensity running
VJ	Vertical Jump
VO_2max	maximal oxygen uptake
V_{vam}-Eval	peak running speed during an incremental field test
WM	wide-mid fielder
Yo-Yo IE2	Yo-Yo Intermittent endurance test 2
Yo-Yo IR1	Yo-Yo Intermittent recovery test 1

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CHAPTER ONE

INTRODUCTION

Background

Competitive soccer play requires the complex interaction between tactical, technical, psychological and physiological components. Most professional soccer academies are seeking to optimize the early physical development of their young players through well-defined talent identification and development procedures (Reilly, Bangsbo, & Franks, 2000). The assessment of the physical determinants on running performance during competitive matches according to age and playing position is a key component to improve talent identification procedures (i.e., player profile determined from game demands) and long-term training interventions (i.e., game specific drills). There is a general belief within the coaching and scientific community that highly developed physical qualities are a prerequisite to compete in high level soccer (Bangsbo, Iaia, & Krustrup, 2008). However, the impact of physical fitness on match running performance and more importantly end-game outcome is highly complex (Mendez-Villanueva & Buchheit, 2011) and many factors have been suggested to moderate the interaction between these variables.

Recent studies have suggested that playing position, maturation status and physical fitness may influence a player's match running performance in youth soccer (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010a; Buchheit, simpson, & Mendez-Villaneuva, 2012; Mendez-Villanueva, Buchheit, Simpson, & Bourdon, 2012; Philippaerts et al., 2006). Recent cross-sectional studies have shown that the magnitude of improvement in match running performance during adolescence is smaller than the magnitude in change in physical qualities; suggesting that game activities maybe more constrained by the competitive demands than physical qualities (Buchheit et al., 2010a; Mendez-Villanueva, Buchheit, Simpson, Peltola, & Bourdon, 2011b). In these recent studies the authors clearly demonstrated that playing position has a strong impact on match running performance, which in turn was greater than the age effect (and its associated changes in physical capacities) (Buchheit et al., 2010a; Mendez-Villanueva, Buchheit, et al., 2011b). It was also shown that the beneficial impact of high-physical fitness on game running performance was likely position-dependent, with attacking players likely to benefit the most from their physical capacities (Buchheit et al., 2010a; Mendez-Villanueva, Buchheit, et al., 2011b).

However, a limitation of these previous studies was that they were taken from cross-sectional research design. To date no studies have examined the longitudinal changes in fitness, maturations status and match running performance in youth soccer players. Longitudinal studies that demonstrate parallel changes in players' physical capacities and match running performance over childhood and adolescence do not exist. Longitudinal studies, as opposed to cross-sectional studies, are particularly valuable because they might provide much greater insights into the development of physical capacities and game-related fitness in young players as they grow and mature.

Purpose of Study

The general purpose of the current thesis was to examine the concurrent development of physical capacities and match running performance during childhood and adolescence in highly-trained soccer players from data that has been collected between 2008 and 2011. The primary aim of this study was to determine if both growth related improvements in physical fitness and match running performance follow a similar path. A secondary aim was to determine whether superior physical fitness systematically (induced by maturation and additional soccer-specific training) translates into greater match running performance.

Significance of Study

As there is relatively limited scientific literature on the influence of physical fitness on match running performance in developing soccer players, this study will provide a better insight and understanding towards these relationships. Together with a better understanding, this information may aid towards the prescription for developing football training content and productive long-term training programs.

Research Aim

The aim of this project was to examine the influence training-induced changes in physical fitness has on actual match running performance in developing soccer players.

Hypothesis

Based on previous cross-sectional data (Buchheit et al., 2010a; Buchheit et al., 2012; Mendez-Villanueva et al., 2012) it was hypothesized that: 1) improvements in physical fitness performances would not be systematically associated with comparable, concurrent changes in match physical performance; and, 2) the fitter player would not consistently present greater match running performance.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This literature review describes the various quantitative and qualitative methods for quantifying match running performance and physical fitness in soccer. Overall this review assists in providing a greater understanding towards the relationship between physical fitness and match running abilities.

Search Strategy and Evaluation of the Quality of Current Evidence

The literature was reviewed to provide a better understanding of the associations between physical fitness capacities and match running performance in soccer players. The literature was drawn from only peer-reviewed journal publications. Electronic databases such as PubMed, MEDLINE, SPORT DISCUS, and Google Scholar were screened for studies in adults and adolescents where one or more fitness test were conducted, and the outcome measured a match running performance variable. The following keywords were used in various combinations: ‘soccer’, ‘football’, ‘match running soccer’, ‘match running football’, ‘match running performance soccer’, ‘match running performance football’, ‘fitness soccer’, ‘fitness football’, ‘physical capacity soccer’, ‘physical capacity football’, ‘physical fitness soccer’, and ‘physical fitness football’. Due to focus on soccer (i.e. association football), this reduced the number of articles retrieved and, consequently, no limit to the search period was supplied. Electronic database searching was supplemented by examining the references of relevant articles. Only full reports published in English were included in the evaluation.

Quality Assessment

A quality assessment list described by Castro-Pinero et al. (2010) was used to rate the selected studies overall quality as detailed below. The list included three items based on number of study subjects, description of the study population and statistical methods (see table 1). Each item was rated from 0 to 2, with 2 being the best score and a total quality score was calculated by counting up the number of positive items (i.e., equaling a total score between 0 and 6). High quality studies were defined when a score greater than 5 was obtained, moderate quality studies were defined when 3 or 4 was obtained and a score lower than 3 was defined as low quality. Three reviewers (BMS, MB and AMV) evaluated the quality of the studies, independently.

Table 1. Quality assessment criteria for match running performance and physical fitness studies.

Grading system parameter	Grade	Criterion
Number of study subjects	0	n ≤ 10
	1	n = 11-50
	2	n ≥ 51
Description of the study population with respect to age, sex, competitive playing standard, playing position	0	Less items than required for grade 1
	1	At least age, sex and competitive playing standard.
	2	More items than required for grade 1
Statistical analysis included in the study	0	Those not included in 1
	1	Correlation analysis
	2	More items than required for grade 1 or Hopkins statistics

Rating for total score: high quality = 5-6, low quality = 3-4, very low quality = 0-2

Search limits

1. Study was a full report published in a peer-reviewed journal,
2. One or more fitness tests were carried out; and,
3. The outcome measure was one of the selected ‘match running performance’ variables.

Quantifying game demands during match play

Quantifying the match demands of soccer players, have traditionally been determined via manual pen and paper or video analysis systems. Due to the laborious process associated with this manual task, there were relatively few match analysis studies conducted. More recently, automated systems such as semi-automatic computerized tracking systems (i.e. ProZone, Amisco, SICS etc.) and the development of micro technology devices including GPS and accelerometers have allowed match demands of soccer competition to be assessed with relative ease. Whilst these analysis systems provide a large amount of information regarding the physical activity profiles (i.e. match running performance), these have most commonly been used to assess factors such as total distance covered, distances travelled in different speed zones (i.e. high speed running, low speed activity etc.), sprint counts, and accelerations / decelerations. The applications of these systems are wide and include: monitoring player progression, guiding post-game recovery interventions, physical performance / match specific fitness assessment.

Whilst, these recent descriptive studies have greatly improved our understanding of the match demands of soccer at different levels, it has been difficult to accurately compare the results of these studies as most have used different criteria for the definition of speed zones, and there have been differences in the measurement accuracy of the various systems. Nonetheless, there have been two general approaches in defining the speed zones for categorizing the physical activity profiles of the players in these studies, i.e., using absolute (Bradley, Mascio, Peart, Olsen, & Sheldon, 2009; Bradley, Sheldon, et al., 2009; Di Salvo et al., 2007; Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Mohr, Krustrup, &

Bangsbo, 2003) and/or relative (Abt & Lovell, 2009; Buchheit et al., 2010a; Dwyer & Gabbett, 2012; Mendez-Villanueva et al., 2012; Hunter et al., 2015, Lovell et al., 2013) speed thresholds.

Comparison of Individualized vs. Absolute Speed Thresholds in Match Activity Profiles

Match activity profiles are typically used to describe in terms of distances traveled and time spent in specific speed zones (i.e., high and low-speed running, etc.). The most common approach to describe time spent in different speed zones has been through the use of arbitrary absolute speed zones. For example, specific speed criteria used to define where high-intensity running begins (i.e. distance travelled > 15 $km \cdot h^{-1}$), have been based on absolute and therefore "player independent" speeds or otherwise known as absolute running threshold. Whilst there has been a lack of consistency in the absolute running speed thresholds used to described the various speed zones (see Figure 2), it remains the most widely adopted approach in research. A more recent approach used to define the speed zones has been designed to account for individual differences in physical capacity amongst players and this approach describes the speed zones according to individually determined physiological thresholds or peak speeds. Both these approaches offer different information to the scientist and coach, and these are discussed below.

While various running speed zones have been reported in the literature (see Figure 2), a common consensus (i.e., different speeds and names are used to highlight work rate zones) as to the most appropriate ones for using in soccer has not been determined.

Nonetheless, these fixed speed zones that are based as arbitrary speeds can be used to describe and compare absolute running demands of a game between individual players. For example, Di Salvo et al. (2007) demonstrated while professional central defenders have been reported to cover less than 700 m above 19.8 $km \cdot h^{-1}$, professional midfielders generally covered more than 900 m above the same absolute speed (See figure 1). Such comparisons allow coaches and scientists to compare the match activity demands of players in different positions and between different levels of play (e.g. youth vs. professional etc.). Furthermore, longitudinal assessment of distance travelled in arbitrary, fixed speed zones in the analysis of match activity profiles further enable scientists and coaches to assess a players progression (in comparison to their peers) during their developing years.

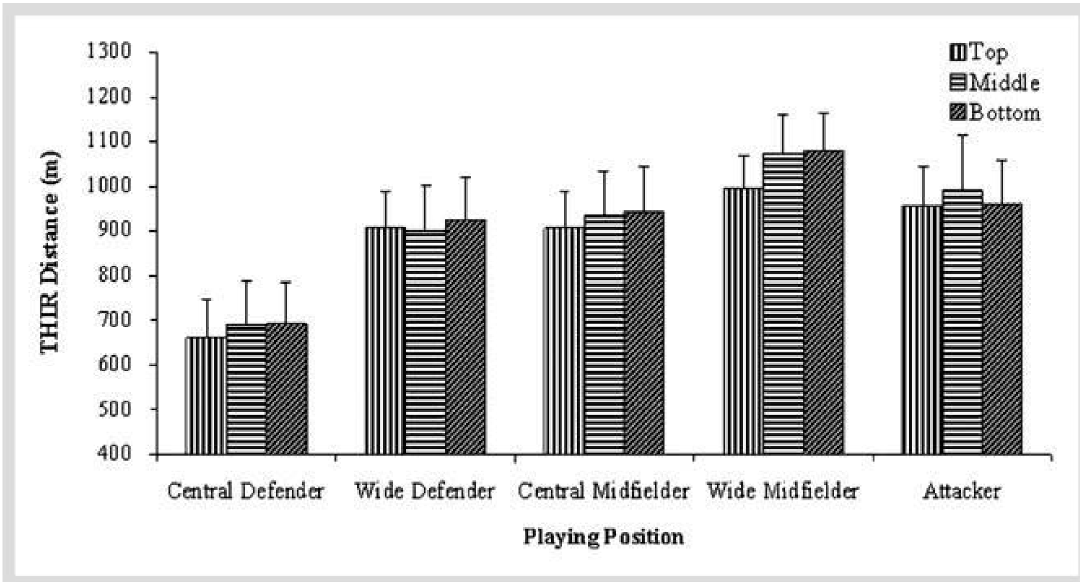

Figure 1. Influence of league position and playing position on total high intensity running (THIR) distance (mean $\pm$ SD). A main effect for league position ($p < 0.05$) and playing position ($p < 0.001$) was observed. A significant interaction between league position and playing position was observed for THIR ($p < 0.05$) (Di Salvo et al., 2007).

One limitation of using arbitrary fixed zones is that it does not inform on the actual internal load (i.e. psycho-physiological load) endured by the player. Indeed, the relationship between absolute running speed and the player's internal physiological load is individual and dependent upon internal characteristics of the player (i.e. age, maturity, fitness, fatigue, mechanics etc.). For example, running at 15 $km \cdot h^{-1}$ can be considered as sub or supra anaerobic threshold for players with anaerobic thresholds at 16 $km \cdot h^{-1}$ and 14 $km \cdot h^{-1}$, respectively. Due to these individual differences, using absolute speed thresholds to analyze match activity profiles of players may not be suitable for examining loads endured by players due to differences in age, fitness and other physical capacities (Abt & Lovell, 2009; Buchheit et al., 2010a; Mendez-Villanueva et al., 2012). Therefore, individual speed thresholds may be a viable method to characterize players' actual running demands during games.

Figure 2 shows a summary of the various speed zones used in recent soccer match analysis papers. These data clearly show the arbitrary speed zones used in these studies could differ substantially from the speeds at which players reach than their own physiological thresholds such as lactate threshold (Abt & Lovell, 2009), maximal aerobic speed and/or maximal sprinting speed (Mendez-Villanueva et al., 2012). These different individualized zones have been used in recent research to describe the relative intensity during match play. To date, however, no studies have examined how changes in fitness and maturation may influence match running performance (analyzed with either absolute of individualized speed zones).

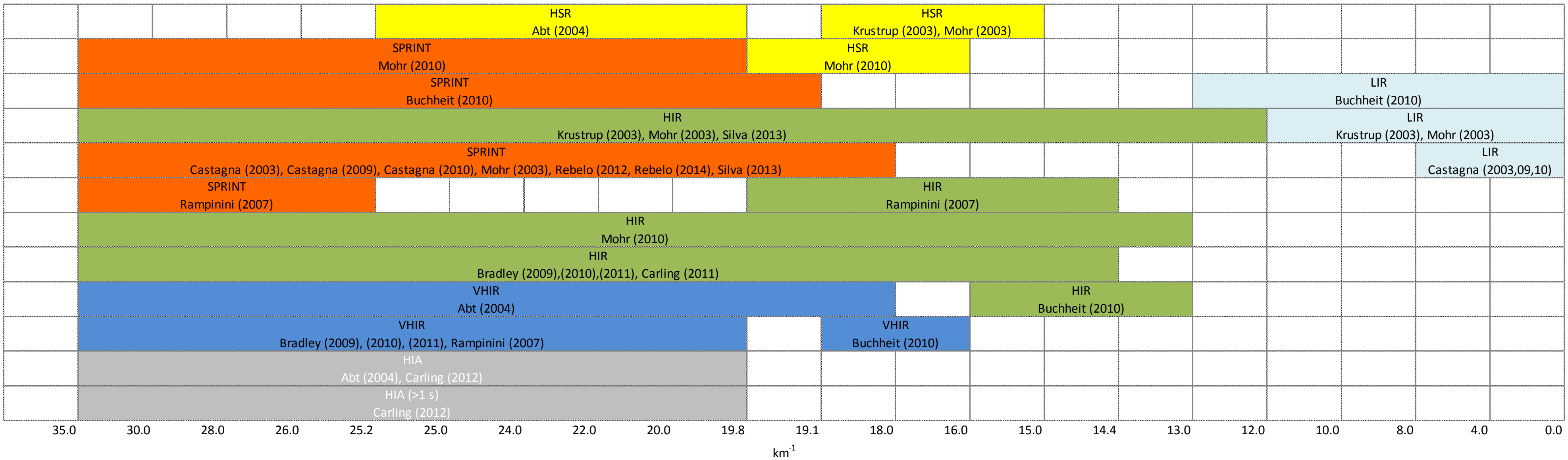

Figure 2. Speed zones described in previous match analysis research.

Analyzing match demands using absolute thresholds

There have been several studies that have used absolute thresholds to describe the match running demands of elite adult soccer players (Di Salvo et al., 2007; Di Salvo et al., 2009; Rampinini, Impellizzeri, Castagna, Coutts, & Wisloff, 2009) and adolescent players (Buchheit et al., 2010a). These data show large differences between playing positions with wide midfielders typically having the highest match activity profile and the central defenders the lowest. Moreover, adult players tend to cover greater distance at high intensities than their younger counterparts. Whilst these observations in cross sectional studies, no longitudinal studies have yet investigated how these relationships may change during adolescence where rapid changes in fitness and maturity status occur.

Analyzing match demands using relative thresholds

More recently, several studies have reported on the match demands of soccer players using individualized, relative threshold zones in their match analysis in both adult (Abt & Lovell, 2009) and youth players (Mendez-Villanueva et al., 2012). However, accurate comparisons between studies remain difficult as the few previous studies that have used this approach have each used different physiological thresholds to determine the match demands. Nonetheless, this approach has been suggested to be useful as it was demonstrated that players differ in the speed at which they begin to run at high-intensity; highlighting the error in making comparisons between players with different fitness characteristics or maturity status. At present however, no studies have examined how the relationships between changes in fitness and maturity characteristics may influence match running performance during puberty.

Whilst the relationship to actual soccer performance (i.e. win/loss) within homogenous groups (i.e. a league or an age group) is not yet fully understood, it does seem that higher levels of soccer require greater match activity (regardless of analysis method used). However, to date there has been no longitudinal information that examines how soccer match activity profiles change with increases with maturation, and fitness within individuals. Future studies are required to examine the within individual changes in match activity performance using both absolute and relative speed zones so that their relationship with maturational and fitness characteristics can be better understood. Such analysis would allow scientists to better understand the contribution of fitness capacities to soccer match running performance in adolescent players (Hunter et al., 2015, Lovell et al., 2013).

Relationships between Match Activity Profile with Technical and Tactical Profiles

Technical and tactical abilities have been reported as more important qualities for overall success in soccer (Rampinini et al., 2009). Specifically, this previous study demonstrated that most successful teams within a league have less high speed running, but greater very high speed running with the ball than the lower ranked counterparts. These results suggest that there are relationships between physical and technical/tactical demands and physical activity profiles. However, it is likely that a player’s fitness is related to the physical profile. Indeed, several studies have shown that players at higher levels of play have increased fitness and show greater physical activity profile. In support, Sirotic and Coutts (2007) showed that increased aerobic fitness (i.e., lactate threshold and maximal oxygen uptake) was related to prolonged, high intensity intermittent running performance in a controlled laboratory setting. Similarly, Rampinini, Impellizzeri, Castagna, Azzalin, Bravo, et al. (2008) recently reported that players with increased fitness, and fatigue resistance to high intensity exercise, also preserved their skilled performance capacity during soccer specific exercise in a laboratory. Collectively, these studies highlight the importance of increased fitness on different aspects of soccer performance, including running capacity and skilled performance. To date however, there have been relatively few studies that have examined the relationship between fitness or fatigue levels and skilled performance in a match setting.

The relationship between variations in physical and skill-related performance have been extensively researched, but mostly in controlled laboratory or field environments using simulated soccer activity and non-elite participants (Rampinini, Impellizzeri, Castagna, Azzalin, Ferrari Bravo, et al., 2008). Due to the high physical demands of soccer, there is evidence of players presenting a decline in physical efforts across playing halves and noticeably towards the end of matches which has previously been suggested to impact upon skill and tactical proficiencies (Mohr, Krustrup, & Bangsbo, 2005; Reilly, Drust, & Clarke, 2008). Indeed, Rampinini et al. (2009) reported a concomitant decline in measures of physical and skill-related performance in the second half of games in professional players competing in the Italian Serie A league, while in contrast (Carling & Dupont, 2011a) found no direct link between decreases in match running performance and skill-related performance in top professional players from the French Ligue 1. From the existing literature, it is difficult to determine whether this is due to a combination of metabolic changes or change in playing style. Notably however, Carling and Dupont (2011) suggested that declines in physical performance are most likely associated with match-related fatigue, whether via tactics, playing formation or score line.

Taken collectively, it seems that sub-elite or developing soccer players (which typically have lower fitness characteristics (Stolen, Chamari, Castagna, & Wisloff, 2005) may be more affected by the match-related fatigue. In contrast, higher level players do not show as large reductions in skill performance, particularly during match play (Carling, 2010). This may be due to increased fitness for improved technical / tactical skills that assist players to compensate for the influence of fatigue. Regardless, of the exact mechanisms underlying these observations, it seems logical that players develop their fitness qualities to improve performance. Notably however, no studies have examined the longitudinal changes in physical fitness, maturation and match running performance in soccer. Future studies are required to examine changes in fitness during adolescence through profiling relative and absolute match activity in soccer players. A greater understanding of these relationships could provide scientists and coaches with information that can be used to guide specific training content during the different phases of maturation.

Measuring fitness in soccer

It is well documented that soccer players require high physical demands due to the multiple brief intense activities and intermittent in nature, such that jumps, tackles, turns, high-speed runs and sprints occur regularly within a game (Stolen et al., 2005). These physical qualities involved in soccer have been studied extensively during the last decade, and it has been established that a large variety of physiological / physical characteristics are important for improved soccer performance. The model below (see figure 3) shows the theoretical relationships between fitness characteristics and soccer performance.

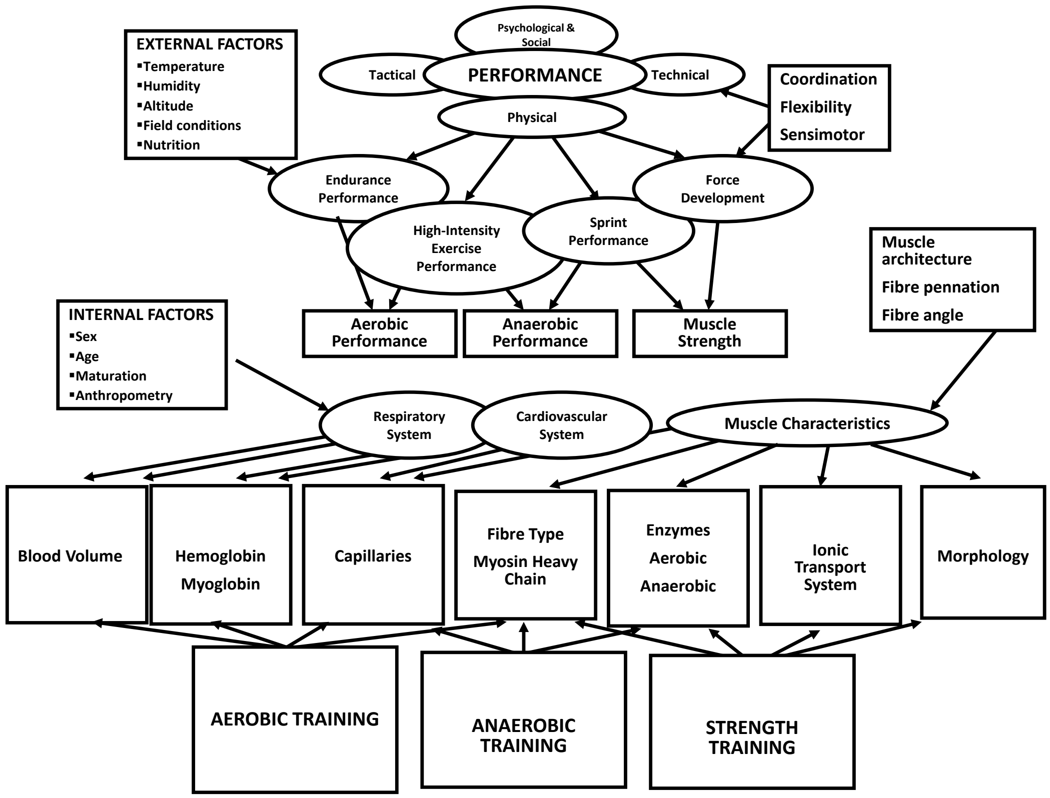

Figure 3. Factors linking training, fitness characteristics and match performance (Adapted from Bangsbo 1996).

Due to the logical relationship between physical fitness and physical performance in soccer match play, it is important for scientists to be able to accurately quantify specific fitness characteristics of players so the evolution of their development can be properly assessed. However, whilst it is generally accepted that physical performance increases with playing level and age (Buchheit et al., 2010a; Mendez-Villanueva, Buchheit, Kuitunen, et al., 2011; Philippaerts et al., 2006; Russell & Tooley, 2012; Vaeyens et al., 2006), it is difficult to accurately compare results from studies in youth soccer players as a myriad of tests have been used in previous work (Table 2). Nonetheless, it is clear that physical fitness should be assessed using specific, valid and reliable tests so that the influences of training and maturation can be assessed.

Variation in physiological changes and their impact on athletic performance

The main physiological qualities associated with athletic performance change dramatically during puberty and adolescence. Adolescents usually experience a growth spurt in stature followed by spurts in muscle mass, and strength (Beunen & Malina, 2008). However, each physiological variable develops at different rates and each is intrinsically linked to maturity or the attainment of 'Peak Height Velocity' (PHV) (Baxter-Jones, 1995; Beunen & Malina, 1988; Beunen & Malina, 2008; Malina, 1994; Pearson, Naughton, & Torode, 2006; Roemmich & Rogol, 1995). Whilst this has not been assessed within individuals, it is likely that maturation will affect soccer match running performance. To account for the variable rate of development amongst individuals, and its influence on soccer match performance, most physiological measures should be expressed relative to the timing of PHV rather than to chronological age (see Figure 4). The expression of physiological development relative to PHV provides more specific information about the timing and magnitude of adolescent spurts in other body dimensions than height and in performance (Beunen & Malina, 2008; Boas, 1892). The following section describes the impact of maturation on PHV and its reported influence in physical qualities that are associated with sport performance such as soccer.

Table 2. Physical performance tests used within the reviewed literature.

Article	Cardio-Respiratory Fitness	Repeated Sprint Ability	Speed	Neuromuscular
Abt (2009)	• Ventilatory threshold			
Bradley (2011)	• Yo-Yo IE2 • Submax Yo-Yo IE2 • GXT (treadmill)			
Buchheit (2010)	• V_{amEval}	• RSA	• 40-m sprint	• CMJ
Carling (2012)		• RSA – 6 x 6s with 20 s passive recovery		
Castagna (2003)	• No test			
Castagna (2009)	• Yo-Yo IR1			
Castagna (2010)	• Yo-Yo IR1 • MSFT • Hoff Test			
Hunter (2015)	• GXT (treadmill) • RCT/MAS		• 40 m Sprint	
Lovell (2013)	• GXT (treadmill) • VT_1/RCT/MAS			
Krustrup (2003)	• Yo-Yo IR1 • HR-speed relationship • GXT (treadmill)			
Mohr (2003)	• Yo-Yo IR1			
Mohr (2010)		• RSA – 3 x 30 m with 25 s active recovery		• Repeated Jump test
Rampinini (2007)	• Modified University of Montreal Track Test	• RSA – 6 x 40 m shuttles (i.e., 20 + 20 m) with 20 s passive recovery		• VJ
Rebelo (2012)	• Yo-Yo IR1 • Yo-Yo IE2 • GXT (treadmill)			
Rebelo (2012)	• Yo-Yo IR1 • Yo-Yo IE2 • GXT (treadmill)			
Silva (2012)	• Yo-Yo IE2		• 30 m Sprint • T-test	• CMJ

GXT – graded exercise test, CMJ – countermovement teat, MAS – maximal aerobic speed, RCT – respiratory compensation threshold, VJ – vertical jump, RSA – repeated sprint ability test, VT_1 – ventilatory threshold YoYo IR1 – YoYo Intermittent Recovery Test (Level 1), YoYo IE1 – YoYo Intermittent Endurance Test (Level 1), YoYo IE2 – YoYo Intermittent Endurance Test (Level 2), V_{amEval} - peak running speed during an incremental field test. (Refer to Table 1. for inclusion criteria).

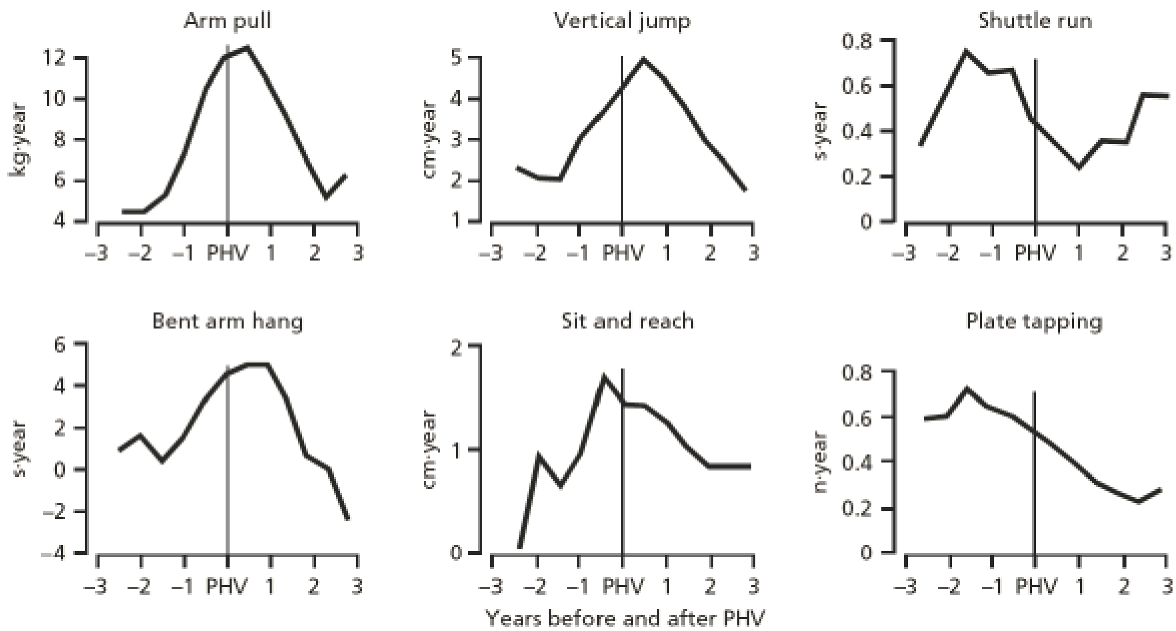

Figure 4 Median velocities of several tests of strength and motor performance aligned on peak height velocity (PHV) in the Leuven Growth Study of Belgian Boys. Velocities for the performance items are plotted as years before and after PHV. Drawn from data reported by Beunen *et al*. (1988).

Peak Height Velocity (PHV)

The adolescent growth spurt commences at about 10 years in girls and 12 years in boys, reaching a peak (PHV) at about 12 years in girls and 14 years in boys and then gradually declines and eventually ceases with the attainment of adult stature. It would be expected that its greatest influence of PHV on soccer performance occurs between 12−14 y in boys.

Peak Weight Velocity (PWV)

Substantial weight gain accompanies the adolescent growth spurt, with PWV generally occurring after PHV (Beunen & Malina, 1988; Pearson et al., 2006; Roemmich & Rogol, 1995). This may not always be the case as, Philippaerts et al. (2006), found PWV to be coincident with PHV in trained, adolescent soccer players. On average PWV occurs between 0.2 and 0.4 years after PHV in boys. These changes may have significant effects on soccer match running performance, particularly in positions that require agility, change of direction and or close body checking / collisions.

Strength/Peak Strength Velocity

Strength development is related to body size and muscle mass (Beunen & Malina, 2008; Jones, 1946). Peak strength velocity (PSV), therefore, is closely related to PWV and PHV. Several studies have shown that PSV follows PHV, with maximum velocities in strength and endurance following PWV. The adolescent spurt (peak velocities) in static strength (arm pull), explosive strength (vertical jump), and muscular endurance (bent arm hang), appears to begin about 1.5 years prior to PHV and reaches a peak 0.5−1.2 years after PHV and 0.8 years after PWV (Beunen & Malina, 2008; Espenschade, 1940; Jones, 1946; Roemmich & Rogol, 1995). Sport specific strength training may affect the timing of PSV, as Philippaerts et al. (2006), found each of the major strength variables to be coincident with PHV in trained, adolescent soccer players.

Speed

Maximum velocities in speed tests (shuttle run and plate tapping) are achieved about 1.5 years prior to PHV (Beunen & Malina, 1988; Katzmarzyk, Malina, & Beunen, 1997). Recently, Philippaerts et al. (2006), found that maximum velocities in speed tests were also coincident with PHV in trained, adolescent soccer players. Improvements in speed during adolescence appear to be related more to changes in skeletal and neuromuscular maturation

(Beunen & Malina, 1988; Espenschade, 1940; Katzmarzyk et al., 1997). The influence of changes in speed on match running performance in youth soccer players are not currently known.

Aerobic Capacity/Aerobic Power

Aerobic power is dependent on body size during growth, (as indicated by the growth curve of relative aerobic power) and has been related to soccer match running performance in several studies (Buchheit et al., 2010a; Helgerud, Christian Engen, Wisløff, & Hoff, 2001; Impellizzeri et al., 2006). Typically, VO_2max begins to increase several years before PHV and continues to increase after PHV. On the other hand relative VO_2max generally begins to decline one year before PHV and continues to decline after PHV. The decline reflects the rapid changes in stature and body mass so that, per unit of body mass, oxygen uptake declines during the growth spurt. Changes in relative aerobic power during adolescence probably reflect changes in body composition and not changes in aerobic function (Beunen & Malina, 2008; Beunen et al., 1992; Kobayashi et al., 1978; Mirwald, Bailey, Cameron, & Rasmussen, 1981; Pearson et al., 2006). Skeletal maturation and absolute aerobic power are significantly related, with early maturing boys demonstrating, a higher absolute VO_2max than late maturing boys except in late adolescence. Another study investigating anthropometrical characteristics, skeletal age and physiological parameters in Portuguese elite youth soccer players, aged 11-14 years, showed that late maturing soccer players had a higher intermittent endurance compared with early maturing players (Figueiredo et al., 2009). Futhermore, Segers et al. (2008) stated that while early maturing youth soccer players possess many physical advantages, late maturing soccer players run as economically as their skeletally more mature teammates. To date no studies have examined how the longitudinal maturational influences on aerobic capacity affect match running performance in youth soccer players.

Anaerobic Power

Anaerobic Power increases at a steady rate during childhood. There is an increased rate of improvement with the onset of puberty (Espenschade, 1940; Falk & Bar-Or, 1993; Inbar & Bar-Or, 1986; Roemmich & Rogol, 1995). Sprint speed and jumping ability, which are important for soccer performance, improve dramatically during adolescence, with the highest rate of improvement occurring between the ages of 13−15 years (le Gall, Beillot, & Rochongar, 2002; Pearson et al., 2006). Improvements in anaerobic power with maturation appear to be related to a number of factors to do with an increase in muscle mass. At present the maturation-induced changes in anaerobic capacities on match running performance in youth soccer players is not yet known.

During adolescence the greatest physiological differences exist between individuals, mainly because of the wide variation in the timing and tempo of the pubertal growth spurt. However, when adjusted to PHV, there appears to be a consistent pattern. For non-athletic adolescents, flexibility, endurance and motor control appear to occur in the years prior to PHV, whilst strength and power qualities tend to develop at their fastest rates following PHV. However, a recent investigation has suggested that for trained, adolescent athletes, estimated velocities for most performance measures reached a peak around the time of PHV (Philippaerts et al., 2006). Whilst these differences tend to be small, they may, in part be influenced by sport-specific training. However, the influence of maturation and timing of PHV on physical fitness of match activity profile in young soccer player has yet to be reported. Future longitudinal studies are required to examine changes in fitness during adolescence affects the relative and absolute match activity profile in soccer players. A greater understanding of these relationships could provide scientists and coaches with information that can be used to guide specific training content during the different phases of maturation.

CHAPTER THREE

METHODS

Hypothesis

Since many factors other than fitness characteristics (i.e. tactics, technical skills and playing position) affect soccer match running performance, it is hypothesized that improvements in physical fitness performances would not be associated with comparable, concurrent changes in match physical performance in a longitudinal study.

Approach to the Problem

The present investigation was used to assess whether an evolution in physical fitness qualities impacted upon match running performance in youth soccer players from a high-performance sports academy (Aspire Academy, Doha, QATAR). The data were gathered over 3 successive years through analysis of match running activity, standard fitness tests assessed included: lower limb explosive strength; maximal sprinting speed; repeated sprint performance and maximal aerobic speed, and basic anthropometric measurements that would allow for assessment of somatic maturity.

Longitudinal analysis was undertaken to assess if: 1) improvements in physical fitness performances would not be systematically associated with comparable, concurrent changes in match running performance; and, 2) the fitter players have greater match running performance.

Subjects

Time-motion match data and physical performance testing were collected in 124 highly-trained youth soccer players (age: 14.5 ±1.3 years, maturity offset: 0.3 ±1.2 years from/to peak height velocity, stature: 163.1 ±9.3 cm and body mass: 50.2 ±9.1 kg and 45.7 ±9.5 mm for sum of 7 skinfolds) belonging to 6 different age groups ranging from Under 13 to Under 18. Players who participated in the study were from a high-performance sports academy (Aspire, Doha, QATAR). The final sample of players from which the data were drawn for analysis (refer to Figure 5) is detailed in the results section. All players, irrespective of the age group, participated on average in ~14 h of combined soccer-specific training and competitive play per week (6-8 soccer training sessions, 1 strength training session, 1-2 conditioning sessions, 1 domestic game per week and 2 international club games every 3 weeks). All players had accumulated a minimum of 3 years of soccer-specific training. Preceding the commencement of the study, all subjects were made aware of the potential risks and benefits associated with participation, and written informed consent and a medical questionnaire were completed by each subject and their parents. Ethical approval was provided from the University Human Research Ethics Committee for all experimental procedures.

Experimental Protocol

Match data was collected on outfield players across international club matches played over a period of 3 years. Every week, two-high level, international club teams (mainly from Europe) visited the academy upon invitation to play against the same aged academy team.

By providing high-level opposition and through keeping the competition format consistent, match-by-match variability in running performance was likely reduced (Rampinini et al. 2007). All matches were performed on two identical 100 x 70 m outdoor natural grass fields using 11 players per side. Playing time was 2 x 35 min for U13 and U14, 2 x 40 min for U15, U16 and U17, and 2 x 45 min for U18.

All players undertook a series of anthropometrical measures and specific fitness components were determined via physical performance tests, testing was conducted three times over the course of each competitive season (October, January and May). To avoid fatigue unduly influencing the results, physical performance tests were performed over two testing sessions (i.e., aerobic test completed during a morning training session (8:00 am) and neuromuscular tests completed during an afternoon session (3:00 pm)). Testing sessions were at least 31 h apart. All physical performance tests were administered on the same indoor synthetic track to maintain standardized testing conditions (22 ±0.5˚C, 55 ±2% relative humidity) throughout the course of the investigation. Prior to each physical performance session, a 20-min standardized warm-up that all players were familiar with was undertaken.

Players and Data Eligibility

To examine whether match running performance can be affected by substantial changes in physical fitness, data from players displaying a substantial increase or decrease (i.e., greater than ½ of a coefficient of variation (CV) (Hopkins et al., 2009), determined prior to the present study, in physical fitness characteristics across 2 consecutive testing sessions were included in the final analysis. Because of the high variability in match-to-match running performance (Di Salvo et al., 2010) , we only retained data from players that performed at least 2 games at the same playing position during each testing period. More precisely, all data from games played between October and mid December were averaged (1st playing period) and allocated to the October testing session (1st testing session, with corresponding physical capacities). Data from games played between mid December and the end of February were averaged (2nd playing period) and allocated to the January testing session (2nd testing session). Finally, data from matches played in March, April or May were averaged (3rd playing period) and allocated to the May testing period (3rd testing session). No games were analyzed from June to September (4th playing period).

Testing Procedures

Anthropometric measurements

All anthropometric measurements were taken during the morning (~8:00 am), by an ISAK accredited anthropometrist. Measures included stretch stature, body mass, sitting height and sum of seven skinfolds (i.e., triceps, subscapular, biceps, supraspinale, abdominal, front thigh and medial calf). Stretch stature was measured using a wall mounted stadiometer (±0.1 cm, Holtain Limited, Crosswell, UK), sitting height with a stadiometer mounted on a purpose built table (±0.1 cm, Holtain Limited, Crosswell, UK), body mass with a digital balance scale (±0.1 kg, ADE Electronic Column Scales, Hamburg, Germany) and skinfold thickness using a set of Harpenden skinfold calipers (±0.1 mm, Baty International, Burguess Hill, UK).

Maturity assessment

Maturity status is an important biological marker when assessing physical development. Mirwald, Baxter-Jones, Bailey, and Beunen (2002) developed a formula to determine somatic maturity, where age at peak height velocity (PHV) represents the time of maximum growth in stature during adolescence. Biological age of maturity (y) was calculated by subtracting the chronological age at the time of measurement from the age at estimated PHV. Thus, a maturity age of -1.0 indicates that the player was measured 1 y before this peak velocity; a maturity of 0 indicates that the player was measured at the time of peak velocity; and a maturity of +1.0 indicates that the participant was measured 1 y after this peak velocity. Ethnicity of players was of Arab origin (i.e., Middle East and North African backgrounds), The effect of ethnicity on the validity of biological maturity estimates using the procedures described above is presently unknown; the equation was therefore assumed to be valid for the present sample (Buchheit et al., 2010b; Mendez-Villanueva et al., 2010). Data derived from a sample of 90 young soccer players (age range: 12.1 – 17.3 years) in our academy showed that age from/to PHV is well correlated (r = 0.69 (90%CL; 0.59 – 0.77) with skeletal age (estimated from a hand and wrist radio-graph; Gilsanz-Ratib's bone age atlas (Gilsanz & Ratib, 2005)).

Physical Performance Tests

Lower Limb Explosive Strength

A vertical countermovement jump (CMJ, cm) with flight time measured with contact mat (KMS, Fitness Technology, South Australia) to calculate jump height was used to assess lower limb explosive strength. Players were instructed to keep their hands on their hips with the depth of the counter movement self-selected. Each trial was validated by visual inspection to ensure each landing was without significant leg flexion. Athletes were encouraged to perform each jump maximally. At least three valid CMJ's were performed separated by a least 25 s of passive recovery, with the best performance recorded.

Maximal Sprinting Speed

Players performed two maximal 40 m sprints, where 10 m splits were recorded using dual beam electronic timing gates (Swift Performance Equipment, Lismore, Australia). Maximal sprinting speed (MSS) was defined as the fastest 10 m split time. Where split times were measured to the nearest 0.01 s. Players commenced each sprint from a standing start, with their foot 0.5 m behind the first timing gate and were instructed to sprint as fast as possible over the full 40 m. Players were free to start when ready, thus eliminating reaction time. Each trial was separated by at least 60 s of recovery with the best performance used as the final result.

Repeated Sprint Performance

All players performed a repeated sprint ability (RSA) test following a 10 min rest break after the 40-m sprint trials. The RSA test consisted of 10 repeated straight-line 30-m sprints separated by 30 s of active recovery (i.e., jogging back to the start line within approximately 25 s in preparation for the next sprint repetition). Time was recorded to the nearest 0.01 s using two sets of electronic timing gates (Swift, Performance Equipment, Lismore, Australia). The same starting position was used for the 40 m sprint were administered. Players were verbally encouraged to run as fast as possible during each of the 10 sprints, while further encouragement was provided during the passive recovery. Mean repeated-sprint time (RSA_{mean}) was determined as a measure of repeated-sprint performance.

Incremental Field Running Test

Players performed an incremental running test to estimate cardiorespiratory fitness and more precisely maximal aerobic speed (MAS). The administered test was a modified version of the University of Montreal Track Test (UMTT, (Leger & Boucher, 1980)) (i.e., the $V_{am\text{-}eval}$ maximal incremental running test, as previously used (Mendez-Villanueva et al., 2010)). The $V_{am\text{-}eval}$ test begins with an initial running speed of 8.5 $km \cdot h^{-1}$ with consecutive speed increments of 0.5 $km \cdot h^{-1}$ each minute until exhaustion. Auditory signals are provided in order to match 20 m intervals delineated by cones around a 200 m indoor athletics track whereby the players much match their running speed. When the player fails to reach the next cone on two consecutive occasions in the required time the test was terminated. Verbal encouragement was given to the players throughout the test by testers and coaching staff.

Anaerobic Speed Reserve

The anaerobic speed reserve (ASR) was quantified as the difference between MSS and $V_{Vam\text{-}eval}$. MSS and $V_{Vam\text{-}eval}$ are empirically determined quantities that are representative of the body's functional limits for sprint and endurance performance, respectively.

Match Running Performance Measurement

A global positioning system (GPS) unit capturing data at 1 Hz (SPI Elite, GPSports, Canberra, Australia) was fitted to the upper back of each player using an adjustable neoprene harness. This GPS system utilized signals from at least three earth orbiting satellites to determine the players position at a given time and therefore allow the calculation of movement speeds and distance traveled (Edgecomb & Norton, 2006).

Despite a possible underestimation of high intensity running distance with the time resolution of 1 Hz (Randers et al., 2010), good accuracy (r = 0.97) and reliability (CV = 1.7%) have been reported for the assessment of short sprints (peak speed) and repeated sprint exercise for this GPS device compared to an infra-red timing system (Barbero Álvarez, Coutts, Granda, Barbero Álvarez, & Castagna, 2010; Coutts & Duffield, 2010). While the accuracy of the GPS units used for total distance has been reported to be good (3-7%), they have shown to be only moderately accurate for assessing high intensity running (11-30%) (Coutts & Duffield, 2010). However, in the absence of a "gold standard" method, the current system has been reported to be capable of measuring individual movement patterns in soccer (Randers et al., 2010). Heart rate (HR) was also continuously measured (1 Hz) throughout the games (SPI Elite, GPSports, Canberra, Australia).

Match Analyses

In total, 736 player-matches were examined over the 109 games. However, as a consequence of the high substitution rate employed with younger players (especially U13 and U14), using data derived from full-games would have excluded these age groups from the analyses. Therefore, data from the first half only were used to increase sample size for within-position analyses and in turn, statistical power. Tactically, all teams used a 4-4-1-1 formation, a variation of 4-4-2 with one of the strikers playing as a "second striker", slightly behind their partner. Since players' role within the team structure changed little during the games analyzed, all players were assigned to one of the 6 positional groups; full-backs (FB, n = 36 different players at this position), centre-backs (CB, n = 26), midfielders and second strikers (MD, n = 48), wide midfielders (WM, n = 43), and strikers (S, n = 19). All match data were analyzed with a custom-built Microsoft Excel program.

Absolute match running zones:

Activity ranges selected for analysis were identical for all categories to allow direct between-age comparisons and were adapted from previous studies on young soccer players (Buchheit, 2008; Zazryn, Cameron, & McCrory, 2006) as follows: 1) total distance covered (TD), 2) low-intensity running (LIR: < 13.0 $km \cdot h^{-1}$), 3) high-intensity running (HIR: 13.1 to 16.0 $km \cdot h^{-1}$), 4) very high-intensity running (VHIR: 16.1 to 19.0 $km \cdot h^{-1}$) and 5) sprinting distance (Sprinting: > 19.1 $km \cdot h^{-1}$). Very high-intensity activities (VHIA) were also calculated as VHIR plus Sprinting. Peak game running (i.e., the highest speed recorded during the game) was also collected.

Relative match running zones:

Five running intensity zones were established to describe each players individual external load in the matches: speed zone 1 (S1): below 60% of $V_{Vam\text{-}eval}$, speed zone 2 (S2): from 61% to 80% of $V_{Vam\text{-}eval}$, speed zone 3 (S3): from 81% to 100% of $V_{Vam\text{-}eval}$, speed zone 4 (S4): from 101% of $V_{Vam\text{-}eval}$ to 30% of ASR and, speed zone 5 (S5): above 31% of ASR. Using these relative speed zones, total distance (i.e., S1+S2+S3+S4+S5), distance run at intensities below $V_{Vam\text{-}eval}$ (i.e., S1+S2+S3) and distance run at intensities above $V_{Vam\text{-}eval}$ (i.e., S4+S5) were calculated. HR data were classified based on percentage of total playing time spent in each of the following intensity zones: HR1, <60% HR_{max}; HR2, 61-70% HR_{max}; HR3, 71-80% HR_{max}; HR4, 81-90% HR_{max}; HR5, >91% HR_{max} (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). To examine the HR-running speed relationship, the average running speed for each given HR zone was also computed.

Statistical Analyses

Data in the text and figures are presented with 90% confidence limits and intervals (CI). All data were first log-transformed to reduce bias arising from non-uniformity error and then analyzed for practical significance using magnitude-based inferences. We used this qualitative approach because traditional statistical approaches often do not indicate the magnitude of an effect, which is typically more relevant to athletic performance than any statistically significant effect (Hopkins et al., 2009). Moreover, this approach is well suited to a smaller sample size, as for some playing positions in the present study (Hopkins et al., 2009). Between-testing periods standardized differences or effect sizes (ES) (90% confidence interval) in locomotor running speeds were calculated using the standard deviations of the first testing session (e.g., October for the October-January period). Threshold values for Cohen ES statistics were >0.2 (small), >0.6 (moderate), and >1.2 (large). Probabilities were also calculated to establish whether the true (unknown) differences were lower, similar or higher than the smallest worthwhile difference or change (0.2 x the between-subject standard deviation, based on Cohen's ES principle). Quantitative chances of higher or lower differences were evaluated qualitatively as follows: <1%, almost certainly not; 1 – 5%, very unlikely; 5 – 25%, unlikely; 25 – 75%, possible; 75 – 95%, very likely; > 99%, almost certain. If the chance of higher or lower differences was > 5%, the true difference was assessed as unclear. Otherwise, we interpreted that the change as the observed change (Hopkins et al., 2009).

RESULTS

Participants

Increased Physical Capacity

From the initial sample of 124 players, 31 (age: 14.1 ±0.9 years, maturity offset: -0.1 ±1.0 years from/to peak height velocity, stature: 162.8 ±8.4 cm and body mass: 49.5 ±8.9 kg) showed a substantial improvement in one or both physical tests over at least 2 consecutive testing periods, and performed at least 2 games in the same playing position during those testing periods. These players were from the U13 (n=4), U14 (n=11), U15 (n=12) and U16 (n=4) teams, respectively. A total of 52 (substantial increase in MSS) and 32 (substantial increase in $V_{Vam\text{-}Eval}$) pairs of data (i.e., data from 9 and 7 players, were used 2–4 times), for a total of 203 player-games analyzed.

Decreased Physical Capacity

Similarly, 13 players (age: 14.3 ±1.2 years, maturity offset: 0.3 ±1.2 years from/to peak height velocity, stature: 166.4 ±9.9 cm and body mass: 52.1 ±9.1 kg) showed a substantial decrease in one or both physical tests performed, following a similar criteria as detailed above. These players belonged to the U13 (n=1), U14 (n=5), U15 (n=6) and U16 (n=4) teams, providing 4 (substantial decrease in MSS) and 12 (substantial decrease in $V_{Vam\text{-}Eval}$) pairs for comparison (i.e., data from 2 players were used 2 times for $V_{Vam\text{-}Eval}$ data) for a total of 78 player-games analyzed.

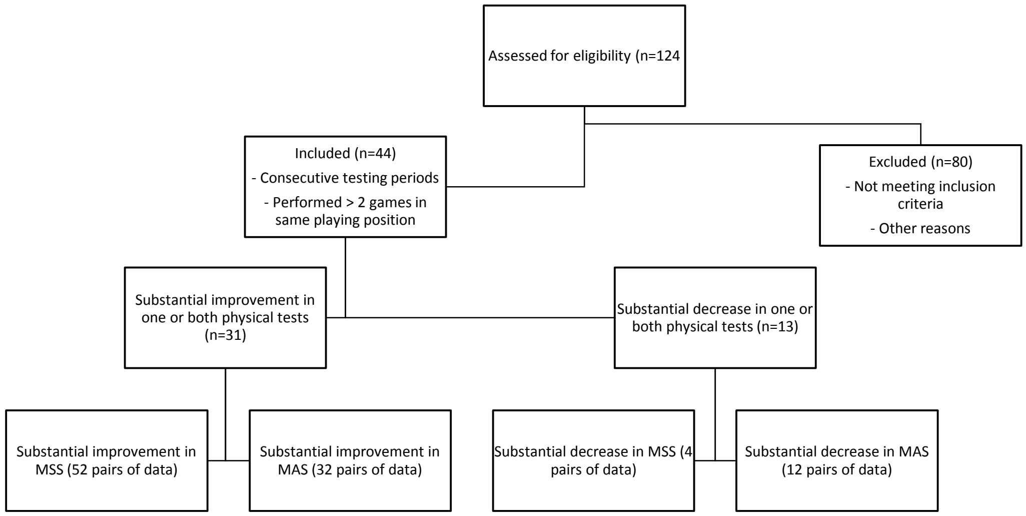

Figure 5 Consort flow chart representing participant's eligibility to study inclusion.

While there was sufficient data to examine the effect of increased physical capacity on game running activity for each position (i.e., ≥3 pairs; see Tables 3 and 5), the influence of decreased physical capacity could only be investigated in a limited number of positions (i.e., when ≥3 players were identified; see Tables 4 and 6). For instance, only 4 midfielders showed substantial decrement in MSS over 2 consecutive periods, while only 3 full-backs, 6 centre-backs and 3 wide midfielders showed substantial decrement in $V_{Vam\text{-}Eval}$. The number of games played for each player, position and testing period are shown in Tables 3-6. All possible age or maturity differences between the positional groups were rated as unclear.

Changes in match running activity in relation to improvements in physical test performance using absolute thresholds.

The improvements in MSS and $V_{Vam\text{-}Eval}$, and associated changes in match running activities expressed using absolute speed thresholds are presented in Table 3. The standardized changes (ES) in physical capacities and match running activities are shown in Figure 6. The changes in match running performance were either non-substantial or of lower magnitude than the changes observed for MSS and MAS. However, the different match running performance measures displayed some slight changes within and changes were also evident between positions.

Table 3 Changes in absolute match running performance variables in highly-trained young soccer players showing substantial improvements in maximal sprinting speed and peak incremental speed within a competitive season.

						On-field running activity (Absolute)														
Position	**Period 1**	**Period 2**	**Δ (%)**	**Period 1 # games**	**Period 2 # games**	**Period 1 m/min**	**Period 2 m/min**	**Δ m/min (%)**	**Period 1 dist LIA**	**Period 2 dist LIA**	**Δ LIA (%)**	**Period 1 dist HIR**	**Period 2 dist HIR**	**Δ HIR (%)**	**Period 1 dist VHIR**	**Period 2 dist VHIR**	**Δ VHIR (%)**	**Period 1 dist SPRT**	**Period 2 dist SPRT**	**Δ SPRT (%)**
maximal sprinting speed (MSS)																				
FB (n=12)	26.9 (26.4;27.5)	28.0 (27.5;28.6)	+4.0 (3.0;5.0) 100/0/0	3 (2;5)	3 (2;4)	100.4 (98.3;102.5)	102.7 (100.6;104.9)	+2.4 (0;5) 68/32/0	83.4 (82.1;84.8)	84.3 (82.9;85.7)	+1.0 (-1;3) 42/55/3	12.3 (11.6;12.9)	13.2 (12.5;13.9)	+7.9 (2;14) 81/19/0	6.9 (6.5;7.3)	7.2 (6.7;7.7)	+3.7 (-4;12) 36/61/3	4.7 (4.2;5.1)	5.2 (4.7;5.8)	+14.2 (1;30) 63/37/0
CB (n=13)	28.3 (28.0;28.7)	29.7 (29.3;30.1)	+4.8 (4.2;5.5) 100/0/0	4 (2;6)	3 (2;5)	98.8 (97.7;99.8)	98.7 (97.4;100.1)	+0.0 (-1.6;1.6) 14/71/15	84.2 (83.5;84.9)	82.8 (81.7;83.8)	-1.7 (-3.2;-0.3) 0/14/85	11.0 (10.4;11.7)	11.7 (11.3;12.2)	+8.2 (3.6;13.0) 86/14/0	5.0 (4.5;5.4)	5.0 (4.8;5.2)	+4.0 (-1.8;10.1) 24/76/0	3.5 (3.2;3.9)	4.3 (3.8;4.7)	+21.0 (10.8;32.1) 99/1/0
MD (n=15)	27.3 (26.9;27.7)	28.5 (28.1;28.9)	+4.6 (4.1;5.1) 100/0/0	3 (2;7)	3 (2;4)	105.3 (103.7;106.9)	106.3 (104.5;108.2)	+1.0 (-0.5;2.5) 34/66/1	86.0 (84.7;87.3)	85.6 (84.2;87.0)	-0.5 (-2.0;1.1) 4/76/20	14.7 (13.9;15.4)	15.7 (14.9;16.6)	+7.4 (1.7;13.4) 78/22/0	7.4 (6.8;8.0)	7.5 (7.0;7.9)	+3.8 (-3.7;11.9) 16/84/1	4.6 (4.1;5.2)	5.0 (4.4;5.6)	+12.4 (-0.1,26.4) 35/65/0
WM (n=8)	27.6 (26.8;28.4)	29.2 (28.4;30.0)	+5.7 (4.7;6.7) 100/0/0	4 (2;5)	3 (2;4)	105.9 (102.8;109.1)	106.5 (102.2;110.8)	-0.0 (-3.1;4.0) 21/68/12	82.6 (81.4;83.8)	81.2 (79.2;83.1)	-1.8 (-4.0;0.4) 2/26/72	14.6 (13.4;15.7)	15.2 (13.7;16.7)	+3.6 (-4.5;12.4) 36/60/4	8.7 (8.0;9.4)	9.4 (8.4;10.4)	+6.2 (-1.8;14.8) 55/44/1	8.8 (7.6;9.9)	10.2 (9.0;11.3)	+19.2 (4.2;36.3) 85/15/0
S (n=4)	28.5 (27.5;29.4)	30.9 (30.4;31.5)	+8.9 (6.1;11.7) 100/0/0	3 (2;4)	4 (2;5)	95.2 (93.8;96.5)	96.9 (95.1;98.7)	+1.8 (0.1;3.5) 83/17/1	78.4 (76.9;79.9)	77.0 (75.6;78.4)	-1.7 (-2.4;-1.1) 0/4/96	9.3 (8.5;10.2)	9.4 (8.7;10.1)	+1.1 (-12.4;16.8) 32/45/23	6.3 (6.2;6.4)	6.3 (6.0;6.6)	-0.9 (-4.6;3.0) 17/40/42	7.4 (7.1;7.8)	10.5 (9.6;11.3)	+39.0 (20.7;60.1) 100/0/0
peak incremental test speed ($V_{vam\text{-}Eval}$)																				
FB (n=9)	14.9 (14.6;15.3)	16.1 (15.9;16.4)	+8.1 (6.5;9.7) 100/0/0	3 (2;4)	3 (2;4)	97.4 (95.4;99.3)	101.7 (99.1;104.4)	+4.4 (1.2;7.6) 94/6/0	82.2 (81.1;83.3)	84.6 (82.9;86.2)	+2.8 (0.4;5.2) 90/10/1	11.2 (10.5;12.0)	12.5 (11.6;13.4)	+10.7 (2.5;19.5) 89/11/0	5.9 (5.3;6.4)	6.6 (6.0;7.2)	+13.1 (5.5;21.1) 93/7/0	4.0 (3.4;4.5)	4.7 (4.1;5.3)	+22.7 (4.9;43.5) 82/18/0
CB (n=7)	15.4 (15.0;15.8)	16.7 (16.3;17.1)	+9.0 (7.0;11.0) 100/0/0	5 (3;6)	3 (2;6)	100.6 (99.6;101.6)	100.4 (99.5;101.3)	-0.1 (-1.5;1.2) 12/66/21	86.6 (85.7;87.5)	86.0 (84.7,87.2)	-0.7 (-2.4;1.0) 7/50/44	10.6 (10.1;11.2)	11.1 (10.5;11.7)	+4.4 (1.1;7.7) 46/54/0	4.6 (4.4;4.8)	4.4 (4.1;4.6)	-5.9 (-10.9;-0.6) 0/18/82	3.3 (3.1;3.6)	3.3 (3.2;3.5)	+2.0 (-4.7;9.1) 24/71/5
MD (n=7)	14.9 (14.2;15.6)	16.1 (15.6;16.6)	+9.0 (5.5;11.5) 100/0/0	3 (2;4)	3 (2;4)	105.4 (102.3;108.5)	107.9 (104.9;110.9)	+2.4 (0.0;5.0) 64/36/0	88.6 (86.3;90.9)	87.4 (84.9;89.9)	-1.4 (-4;1) 1/53/46	14.0 (12.6;15.4)	16.3 (15.0;17.6)	+18.4 (6.7;31.4) 94/6/0	6.7 (5.7;8.7)	7.7 (7.0;8.4)	+1.0 (-1.0;3.0) 65/27/9	2.8 (2.3;3.3)	4.2 (3.3;3.7)	+54.1 (27.7;86) 100/0/0
WM (n=6)	16.1 (15.6;16.6)	17.1 (16.6;17.6)	+6.0 (5.1;7.4) 100/0/0	4 (2;5)	3 (2;4)	103.0 (100.3;105.7)	103.9 (98.7;109.1)	+0.5 (-4.0;5.0) 29/54/17	81.7 (80.4;83.0)	79.8 (77.6;82.1)	-2.4 (-5.2;0.4) 2/20/78	13.3 (12.5;14.2)	14.4 (12.6;1.1)	+5.2 (-4.3;15.6) 56/39/5	8.0 (7.5;8.6)	8.9 (7.6;10.1)	+6.9 (-2.4;17.0) 65/33/2	8.0 (7.0;8.9)	9.7 (8.3;11.2)	+21.3 (5.5;39.6) 90/10/0
S (n=3)	13.9 (13.4;14.4)	15.9 (15.7;16.2)	+14.4 (8.4;21.5) 100/0/0	3 (2;4)	3 (2;5)	94.6 (92.9;96.4)	97.9 (95.4;100.3)	+3.4 (2.3;4.4) 100/0/0	78.9 (77.1;80.8)	77.8 (75.9,79.7)	-1.4 (-2.2;-0.6) 0/62/38	8.5 (8.1;8.8)	9.6 (8.6;10.6)	+12.8 (-2.0;29.8) 87/9/4	6.2 (6.1;6.4)	6.1 (5.7;6.6)	-2.2 (-7.2;3.1) 10/34/56	7.3 (6.8;7.7)	10.4 (9.1;11.7)	+41.3 (15.4;73.2) 99/1/0

The number of games per testing period (separated by 4-5 months, see Methods, Period 1 and 2) are displayed as mean (range). Mean values (90% confidence limits), mean percentage changes (90% confidence limits) and chance for greater/similar/lower values in the amount of meters per minute ($m{\cdot}min^{-1}$), distance covered in low intensity activity (LIA, $m{\cdot}min^{-1}$), distance covered in high intensity running (HIR, $m{\cdot}min^{-1}$), distance covered in very high intensity running (VHIR, $m{\cdot}min^{-1}$) and distance covered in sprinting (SPRT, $m{\cdot}min^{-1}$) for players showing substantial increases in maximal sprinting speed (MSS, $km.h^{-1}$) and peak incremental speed during the Vam-Eval test ($V_{vam\text{-}Eval}$, $km.h^{-1}$) over two consecutive testing periods. FB: full-backs, CB: Centre-backs, MD: midfielders, WM: wide midfielders and S: strikers. Note that the present results related to first half data only.

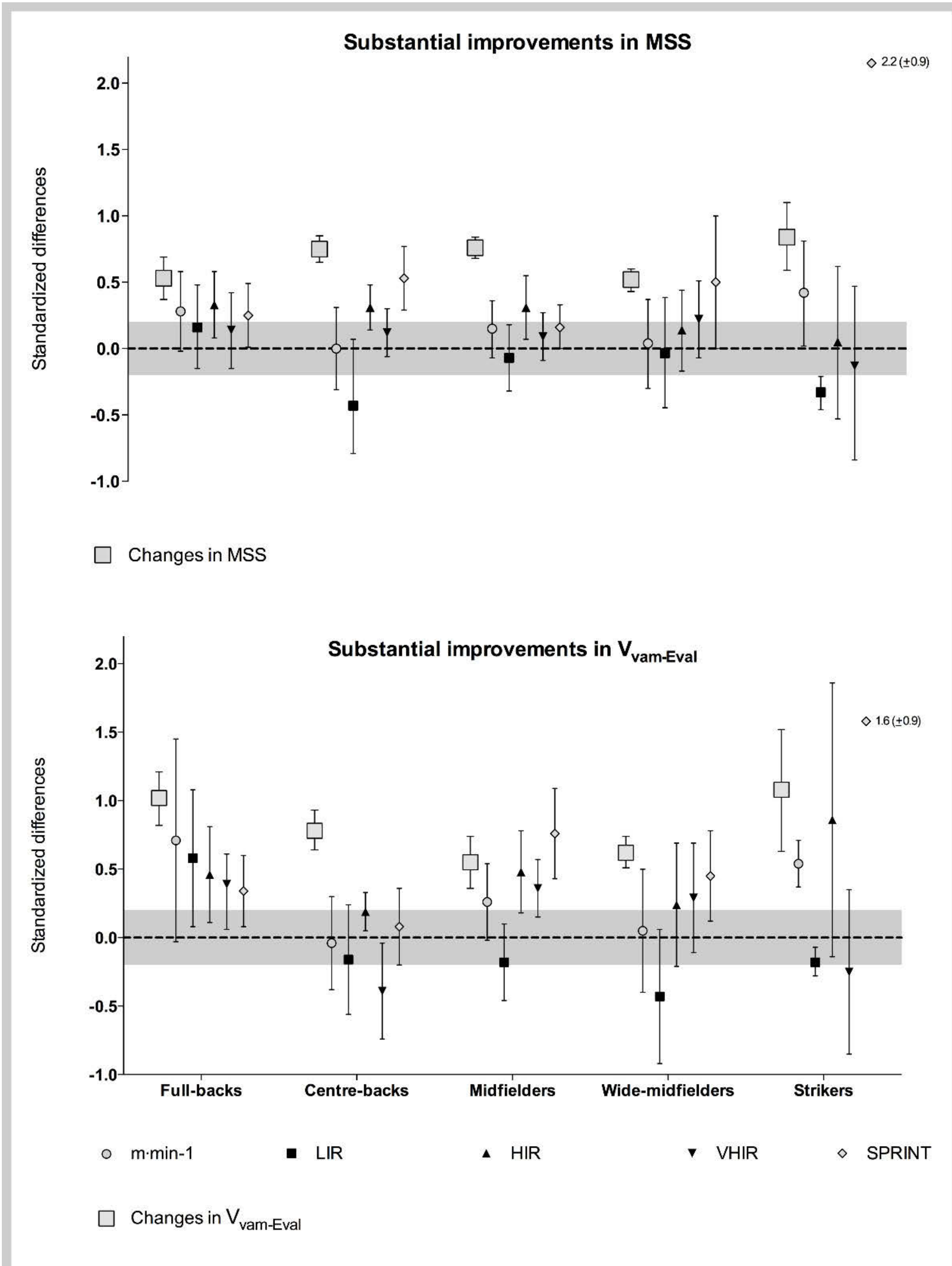

Figure 6 Standardised changes in physical capacities (Maximal sprinting speed, MSS, upper panel, or peak running velocity during the incremental test, $V_{vam\text{-}Eval}$, lower panel) and associated changes in absolute match running performance variables (amount of meters per minute (m·min^{-1}), distance covered in low intensity activity (LIA), distance covered in high intensity running (HIR), distance covered in very high intensity running (VHIR) and distance covered in sprinting (SPRT) for players showing a substantial increase in a given physical capacity over two consecutive testing periods. Note that the present results related to first half data only.

Changes in match running activity in relation to improvements in physical test performance using relative thresholds

The improvements in MSS and $V_{Vam\text{-}Eval}$ performance and their associated changes in match running activities determined using relative thresholds are presented for each position in Table 4. The standardized changes (ES) in physical capacities and match running activities are shown in Figure 7. Overall, most of the match running performance measures were either unchanged or decreased substantially in response to an increase in MSS and/or MAS. The different match running performance measures displayed variations within and changes were also evident between positions.

Changes in match running activity in relation to impairments in physical test performance using absolute thresholds

The changes in match running activities using absolute thresholds in the group for the players showing decreased MSS and $V_{Vam\text{-}Eval}$ performance are presented for each position in Table 5. The standardized changes (ES) in physical capacities and match running activities are shown in Figure 8. In general, most of the match running performance measures were either unchanged or increased substantially in response to a decrease in MSS and/or MAS. Some slight variations remained between the different match running performance measures and also changes between positions.

Table 4. Changes in relative match running performance variables in highly-trained young soccer players showing substantial improvements in maximal sprinting speed and peak incremental speed within a competitive season.

						On-field running activity (Relative)																	
Position	Period 1	Period 2	Δ (%)	Period 1 # games	Period 2 # games	Period 1 dist 0-60% MAS	Period 2 dist 0-60% MAS	Δ 0-60% MAS (%)	Period 1 dist 61-80% MAS	Period 2 dist 61-80% MAS	Δ 61-80% MAS (%)	Period 1 dist 81-100% MAS	Period 2 dist 81-100% MAS	Δ 81-100% MAS (%)	Period 1 dist 101-30% ASR	Period 2 dist 101-30% ASR	Δ 101-30% ASR (%)	Period 1 dist > 31% ASR	Period 2 dist > 31% ASR	Δ > 31% ASR (%)	Period 1 dist > 100% MAS	Period 2 dist > 100% MAS	Δ > 100% MAS (%)
maximal sprinting speed (MSS)																							
FB (n=12)	26.9 (26.4;27.5)	28.0 (27.5;28.6)	+4.0 (3;5) 100/0/0	3 (2;5)	3 (2;4)	57.9 (56.9;59.0)	60.8 (59.5;62.0)	+4.9 (2.6;7.3) 99/1/0	22.7 (21.6;23.7)	23.0 (21.9;24.2)	+1.7 (-2.9;6.5) 22/76/3	14.5 (13.9;15.1)	14.3 (13.7;15.0)	-1.4 (-6.0;3.5) 5/71/24	8.0 (7.7;8.2)	7.6 (6.9;8.2)	-8.3 (-15.6;-0.4) 1/9/89	4.5 (4.1;4.9)	4.2 (3.6;4.9)	-9.1 (-20.84.3) 2/40/58	12.4 (12.0;12.9)	11.8 (10.7;12.9)	-9.0 (-16.0;-1.5) 1/9/91
CB (n=13)	28.3 (28.0;28.7)	29.7 (29.3;30.1)	+4.8 (4.2;5.5) 100/0/0	4 (2;6)	3 (2;5)	54.6 (50.8;58.3)	52.7 (47.8;57.6)	-4.5 (-8.7;-0.1) 1/16/83	21.9 (20.4;23.5)	19.5 (17.6;21.4)	-12.6 (-18.7;6.1) 0/1/99	12.1 (11.1;13.2)	11.2 (10.0;12.4)	-9.0 (-17.3;0) 1/19/80	5.7 (5.1;6.4)	6.3 (5.4;7.2)	+10.6 (-3.6;27.0) 51/48/1	2.7 (2.4;3.0)	3.7 (2.7;4.7)	+16.2 (-2.0;37.9) 73/26/1	8.4 (7.5;9.4)	10.0 (8.3;11.7)	+13.9 (-0.7;30.6) 68/31/0
MD (n=15)	27.3 (26.9;27.7)	28.5 (28.1;28.9)	+4.6 (4.1;5.1) 100/0/0	3 (2;7)	3 (2;4)	58.6 (56.6;60.6)	60.0 (58.3;61.7)	+2.7 (0.2;5.2) 38/62/0	23.4 (22.4;24.4)	24.8 (23.4;26.1)	+5.0 (0.6;9.6) 66/34/0	16.7 (15.9;17.4)	16.7 (15.7;17.8)	-1.4 (-8.0;5.7) 11/60/29	9.4 (8.5;10.2)	9.0 (8.0;9.9)	-6.1 (-12.7;1.0) 0/69/31	4.1 (3.6;4.5)	3.8 (3.4;4.2)	-1.3 (-11.5;10.1) 0/98/11	13.4 (12.2;14.6)	12.7 (11.5;14.0)	-6.1 (-11.3;-0.6) 0/79/21
WM (n=8)	27.6 (26.8;28.4)	29.2 (28.4;30.0)	+5.7 (4.7;6.7) 100/0/0	4 (2;5)	3 (2;4)	61.4 (59.6;63.1)	63.0 (61.1;64.9)	+2.7 (-0.5;5.9) 63/36/1	23.8 (22.1;25.5)	23.2 (20.6;25.8)	-4.5 (-11.4;2.9) 2/54/44	14.5 (13.8;15.2)	14.8 (13.8;15.8)	+1.4 (-6.2;9.7) 34/51/15	8.6 (7.6;9.6)	9.2 (8.3;10.1)	+10.0 (-7.4;30.8) 52/45/4	6.4 (5.9;7.0)	5.8 (5.2;6.3)	-9.6 (-22.2;5.1) 3/32/64	15.1 (13.6;6.5)	15.0 (13.8;16.2)	+2.3 (-12.4;19.4) 27/59/14
S (n=4)	28.5 (27.5;29.4)	30.9 (30.4;31.5)	+8.9 (6.1;11.7) 100/0/0	3 (2;4)	4 (2;5)	55.4 (53.5;57.4)	60.6 (60.2;60.9)	+9.5 (5.8;13.3) 100/0/0	16.1 (15.3;16.9)	15.6 (14.7;16.6)	-2.9 (-5.2;-0.6) 0/44/56	11.6 (11.1;12.2)	10.5 (9.7;11.4)	-10.0 (-18.9;-0.1) 2/8/90	9.3 (9.0;9.5)	8.6 (8.3;8.9)	-7.1 (-11.9;-2.0) 1/3/96	8.4 (6.9;10.0)	7.8 (7.0;8.5)	-3.3 (-27.7;29.2) 19/49/32	17.7 (15.9;19.5)	16.4 (15.5;17.4)	-6.1 (-19.8;9.9) 9/39/51
peak incremental test speed ($V_{vam-Eval}$)																							
FB (n=9)	14.9 (14.6;15.3)	16.1 (15.9;16.4)	+8.1 (6.5;9.7) 100/0/0	3 (2;4)	3 (2;4)	54.7 (53.6;55.8)	61.2 (59.8;62.5)	+11.7 (9.1;14.5) 100/0/0	21.5 (20.6;22.3)	23.4 (22.2;24.7)	+8.3 (2.4;14.6) 94/6/0	14.5 (13.8;15.2)	13.5 (12.7;14.2)	-7.7 (-14.9;0) 30696.0	8.6 (8.0;9.1)	6.8 (6.3;7.3)	-21.5 (-27.2;-15.4) 0/0/100	4.3 (3.8;4.8)	3.5 (3.2;3.8)	-17.2 (-28.5;-4.2) 0/11/88	12.9 (12.2;13.6)	10.3 (9.5;11.1)	-21.2 (-26.4;15.8) 0/0/100
CB (n=7)	15.4 (15.0;15.8)	16.7 (16.3;17.1)	+9.0 (7;11) 100/0/0	5 (3;6)	3 (2;6)	58.0 (56.1;59.9)	64.2 (62.4;66.0)	+10.9 (7.9;13.9) 100/0/0	24.3 (23.8;24.8)	23.7 (23.0;24.5)	-2.3 (-6.0;1.6) 5/35/60	13.3 (12.8;13.9)	11.1 (10.7;11.5)	-2.8 (-5.0;-2.0) 36161.0	6.6 (5.9;7.4)	4.2 (3.7;4.7)	-34.8 (-42.0;-26.7) 0/0/100	2.9 (2.5;3.3)	2.2 (2.0;2.4)	-20.6 (-29.8;-10.2) 0/5/95	9.6 (8.5;10.6)	6.4 (5.6;7.1)	-31.1 (-38.2;-23.2) 0/0/100
MD (n=7)	14.9 (14.2;15.6)	16.1 (15.6;16.6)	+9.0 (5.5;11.5) 100/0/0	3 (2;4)	3 (2;4)	56.6 (52.8;60.5)	59.7 (56.9;62.5)	+6.2 (1.0;11.6) 73/27/0	23.6 (21.4;25.7)	27.2 (24.9;29.4)	+15.4 (8.8;22.5) 99/1/0	17.3 (16.4;18.3)	17.0 (14.9;19.0)	-6.3 (-17.1;5.8) 25104.0	9.6 (8.2;11.1)	8.6 (6.9;10.3)	-15.3 (-24.8;-4.7) 0/22/78	3.8 (2.8;4.8)	4.0 (3.0;5.0)	+13.9 (-9.0;42.7) 18/81/0	13.4 (11.0;15.9)	12.6 (10.0;15.2)	-9.7 (-19.9;1.7) 0/69/31
WM (n=6)	16.1 (15.6;16.6)	17.1 (16.6;17.6)	+6.0 (5.1;7.4) 100/0/0	4 (2;5)	3 (2;4)	59.1 (57.7;60.5)	63.5 (61.0;66.0)	+7.2 (5.2;9.2) 100/0/0	22.1 (20.4;23.8)	21.0 (18.2;23.8)	-7.4 (-15.4;1.3) 1/31/68	14.1 (13.5;14.7)	14.1 (12.9;15.2)	-1.2 (-9.9;8.2) 22/41/37	9.2 (8.1;10.3)	8.4 (7.4;9.4)	-6.0 (-20.3;10.7) 6/57/37	6.5 (6.0;7.1)	5.8 (5.1;6.6)	-12.4 (-26.6;4.5) 3/23/74	15.7 (14.2;17.3)	14.2 (12.9;15.6)	-8.0 (-21.9;8.2) 5/43/52
S (n=3)	13.9 (13.4;14.4)	15.9 (15.7;16.2)	+14.4 (8.4;21.5) 100/0/0	3 (2;4)	3 (2;5)	54.1 (52.1;56.1)	60.3 (59.9;60.8)	+11.7 (7.3;16.4) 100/0/0	16.3 (15.3;17.3)	16.1 (14.9;17.4)	-1.4 (-3.9;1.2) 0/96/4	11.0 (10.9;11.1)	10.8 (9.6;12.0)	-3.2 (-13.3;8.1) 27/6/67	9.4 (9.1;9.7)	8.8 (8.4;9.2)	-6.5 (-13.4;1.0) 3/12/85	9.2 (7.4;11.0)	7.9 (6.8;9.0)	-10.6 (-40.4;30.4) 13/45/42	18.6 (16.5;20.7)	16.7 (15.3;18.1)	-9.3 (-27.4;13.4) 9/34/54

The number of games per testing period (separated by 4-5 months, see Methods, Period 1 and 2) are displayed as mean (range). Mean values (90% confidence limits), mean percentage changes (90% confidence limits) and chance for greater/similar/lower values in the amount of distance covered below 60% maximal aerobic speed (dist 0-60% MAS, $m{\cdot}min^{-1}$), distance covered from 61 to 80% MAS (dist 61-80% MAS, $m{\cdot}min^{-1}$), distance covered from 101% of MAS to 30% anaerobic speed reserve (dist 101-30% ASR, $m{\cdot}min^{-1}$), distance covered above 31% ASR (dist >31% ASR, $m{\cdot}min^{-1}$) and distance covered above 100% MAS (dist >100% MAS, $m{\cdot}min^{-1}$) for players showing substantial increases in maximal sprinting speed (MSS, $km.h^{-1}$) and peak incremental speed during the Vam-Eval test ($V_{vam-Eval}$, $km.h^{-1}$) over two consecutive testing periods. FB: full-backs, CB: centre-backs, MD: midfielders, WM: wide-midfielders and S: strikers. Note that the present results related to first half data only.

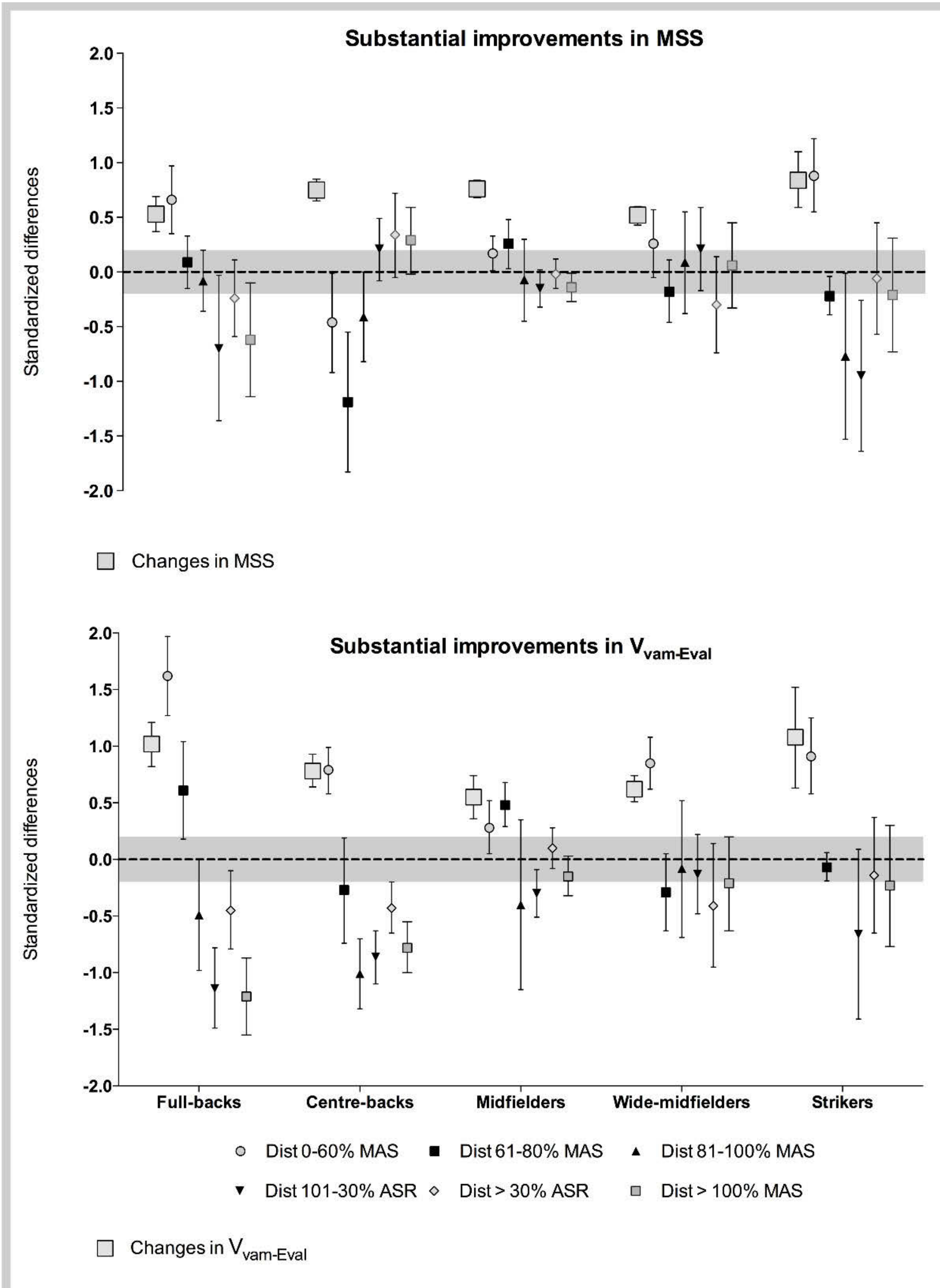

Figure 7. Standardised changes in physical capacities (Maximal sprinting speed, MSS, upper panel, or peak running velocity during the incremental test, $V_{vam\text{-}Eval}$, lower panel) and associated changes in relative match running performance variables (distance covered below 60% maximal aerobic speed (dist 0-60% MAS), distance covered from 61 to 80% MAS (dist 61-80% MAS), distance covered from 101% of MAS to 30% anaerobic speed reserve (dist 101-30% ASR), distance covered above 31% ASR (dist > 31% ASR) and distance covered above 100% MAS (dist > 100% MAS)) for players showing a substantial increase in a given physical capacity over two consecutive testing periods. Note that the present results related to first half data only.

Table 5. Changes in absolute match running performance variables in highly-trained young soccer players showing substantial decrements in maximal sprinting speed and peak incremental speed within a competitive season.

											On-field running activity (Absolute)									
Position	**Period 1**	**Period 2**	**Δ (%)**	**Period 1 # games**	**Period 2 # games**	**Period 1 m/min**	**Period 2 m/min**	**Δ m/min (%)**	**Period 1 dist LIA**	**Period 2 dist LIA**	**Δ LIA (%)**	**Period 1 dist HIR**	**Period 2 dist HIR**	**Δ HIR (%)**	**Period 1 dist VHIR**	**Period 2 dist VHIR**	**Δ VHIR (%)**	**Period 1 dist SPRT**	**Period 2 dist SPRT**	**Δ SPRT (%)**
maximal sprinting speed (MSS)																				
MD	23.3	22.7	-2.3	3	3	104.2	108.0	+3.8	87.9	89.6	+2.1	12.4	14.5	+18.8	6.0	7.7	+28.6	3.9	3.9	+8.4
(n=4)	(20.7;25.8)	(20.4;25.1)	(-3.1;-1.6)	(2;4)	(3;3)	(100.6;107.8)	(105.3;110.7)	(0.3;8.0)	(84.3;91.5)	(87.5;91.7)	(-0.3;4.5)	(11.1;13.7)	(13.6;16.5)	(-0.9;42.3)	(5.3;6.8)	(6.9;8,5)	(3.2,60.2)	(2.5;5.2)	(3.0;4.7)	(-12.6;34.4)
			0/100/0					78/21/1			43/56/0			85/13/2			91/8/1			13/86/1
peak incremental test speed ($V_{vam\text{-}Eval}$)																				
FB	16.7	16.0	-3.8	2	3	104.3	104.2	-0.1	86.6	84.5	-2.3	12.8	13.4	+3.4	8.0	8.0	-3.6	4.9	6.3	+32.1
(n=3)	(16.6;16.7)	(16.0;16.1)	(-4.4;-3.2)	(2;3)	(2;4)	(99.2;109.3)	(101.9;106.5)	(-3.1;3.3)	(83.0;90.1)	(84.1;84.8)	(-6.3;1.8)	(11.0;14.7)	(11.2;15.7)	(-5.0;12.6)	(7.3;8.7)	(6.5;9.4)	(-29.5;31.9)	(5.1;5.6)	(6.0;6.6)	(12.8;54.7)
			0/0/100					8/85/7			4/47/49			15/83/2			31/22/47			97/3/0
CB	16.3	15.4	-5.9	5	3	99.8	100.2	-0.4	85.1	82.2	-3.5	11.6	13.0	+12.2	4.7	6.2	+29.1	3.1	5.0	+55.7
(n=6)	(16.0;16.6)	(14.9;15.8)	(-7.4;-4.5)	(2;6)	(2;3)	(98.3;101.3)	(97.9;102.4)	(-1.9;2.7)	(84.2;86.0)	(80.8;83.6)	(-5.5;-1.3)	(10.8;12.4)	(11.6;14.4)	(4.4;20.5)	(4.3;5.1)	(5.1;7.3)	(21.9;36.8)	(2.8;3.4)	(4.2;5.8)	(44.3;68.0)
			0/0/100					28/59/13			0/2/98			92/8/0			100/0/0			100/0/0
WM	18.3	17.3	-5.3	2	2	113.5	110.8	-2.1	86.4	85.0	-1.7	17.5	15.9	-9.4	10.1	9.6	-5.4	9.6	10.0	+12.8
(n=3)	(18.1;18.5)	(17.2;17.5)	(-7.0;-3.5)	(2;3)	(2;3)	(106.8;120.1)	(107.0;114.7)	(-8.9;5.1)	(84.6;86.3)	(84.7;85.3)	(-4.3;1.1)	(15.1;19.9)	(13.8;17.9)	(-24.5;8.8)	(8.5;11.6)	(8.0;11.2)	(-21.4;13.8)	(6.2;12.9)	(8.5;11.5)	(-17.9;54.9)
			0/0/100					10/51/39			4/34/62			6/35/59			10/51/39			36/58/6

The number of games per testing period (separated by 4-5 months, see Methods, Period 1 and 2) are displayed as mean (range). Mean values (90% confidence limits), mean percentage changes (90% confidence limits) and chance for greater/similar/lower values in the amount of meters per minute ($m \cdot min^{-1}$), distance covered in low intensity activity (LIA, $m \cdot min^{-1}$), distance covered in high intensity running (HIR, $m \cdot min^{-1}$), distance covered in very high intensity running (VHIR, $m \cdot min^{-1}$) and distance covered in sprinting (SPRT, $m \cdot min^{-1}$) for players showing a substantial decrease in maximal sprinting speed (MSS, $km.h^{-1}$) and peak incremental speed during the Vam-Eval test ($V_{vam\text{-}Eval}$, $km.h^{-1}$) over two consecutive testing periods. FB: full-backs, CB: centre-backs, MD: midfielders, WM: wide-midfielders and S: strikers. Note that the present results related to first half data only.

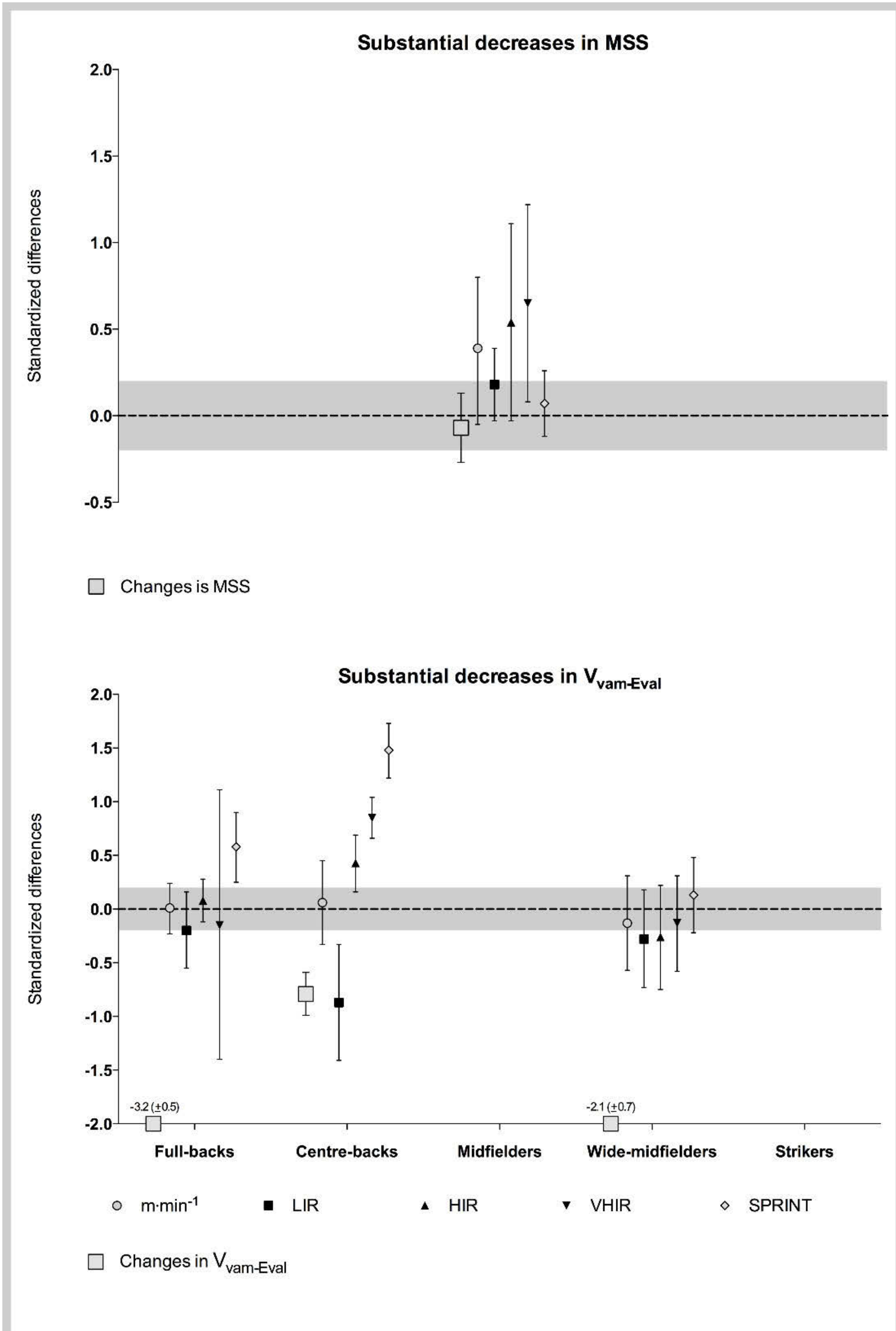

Figure 8. Standardised changes in physical capacities (Maximal sprinting speed, MSS, upper panel, or peak running velocity during the incremental test, $V_{vam\text{-}Eval}$, lower panel) and associated changes in absolute match running performance variables (amount of meters per minute ($m{\cdot}min^{-1}$), distance covered in low intensity activity (LIA), distance covered in high intensity running (HIR), distance covered in very high intensity running (VHIR) and distance covered in sprinting (SPRT) for players showing a substantial decrease in a given physical capacity over two consecutive testing periods. Note that the present results related to first half data only.

Changes in match running activity in relation to impairments in physical test performance using relative thresholds

The changes in match running activities using relative thresholds for players with reduced MSS and $V_{Vam\text{-}Eval}$ performance are shown in Table 6. The standardized changes (ES) in physical capacities and match running activities are shown in Figure 9. In general, most of the match running performance measures were either unchanged or increased substantially in response to a decrease in MSS and/or MAS. The increase in match running performance measures tended to be of greater magnitude than those observed considering absolute thresholds. Some slight variations remained between the different match running performance measures and also changes between positions.

Table 6. Changes in relative match running performance variables in highly-trained young soccer players showing substantial decrements in maximal sprinting speed and peak incremental speed within a competitive season.

						On-field running activity (Relative)																	
Position	Period 1	Period 2	Δ (%)	Period 1 # games	Period 2 # games	Period 1 dist 0-60% MAS	Period 2 dist 0-60% MAS	Δ 0-60% MAS (%)	Period 1 dist 61-80% MAS	Period 2 dist 61-80% MAS	Δ 61-80% MAS (%)	Period 1 dist 81-100% MAS	Period 2 dist 81-100% MAS	Δ 81-100% MAS (%)	Period 1 dist 101-30% ASR	Period 2 dist 101-30% ASR	Δ 101-30% ASR (%)	Period 1 dist > 31% ASR	Period 2 dist > 31% ASR	Δ > 31% ASR (%)	Period 1 dist > 100% MAS	Period 2 dist > 100% MAS	Δ > 100% MAS (%)
maximal sprinting speed (MSS)																							
MD	23.3	22.7	+4.0	3	3	57.7	59.0	+1.8	22.5	24.2	+10.3	15.2	18.4	+20.0	9.1	11.2	+19.4	4.8	5.6	+10.2	13.9	16.8	+16.2
(n=4)	(20.7;25.8)	(20.4;25.1)	(-3.1;-1.6)	(2;4)	(3;3)	(54.7;60.8)	(54.9;63.0)	(-1.1;4.9)	(19.3;25.7)	(23.5;24.9)	(-2.6;25.0)	(14.5;16.0)	(16.9;20.0)	(9.4;31.8)	(8.4;9.9)	(9.4;13.1)	(7.3;33.0)	(4.5;5.0)	(4.4;6.8)	(-11.5;37.1)	(13.0;14.8)	(13.8;19.9)	(0.6;34.2)
			0/100/0					14/86/0			49/50/1			99/1/0			97/3/0			67/18/14			89/9/2
peak incremental test speed ($V_{vam\text{-}Eval}$)																							
FB	16.7	16.0	-3.8	2	3	63.2	60.7	-4.0	24.5	22.5	-7.0	13.8	14.8	+6.2	7.7	9.4	+21.3	3.0	4.7	+62.9	10.7	14.2	+34.1
(n=3)	(16.6;16.7)	(16.0;16.1)	(-4.4;-3.2)	(2;3)	(2;4)	(62.5;63.9)	(59.9;61.5)	(-6.7;-1.3)	(21.3;27.7)	(21.4;23.6)	(-15.6;2.6)	(12.1;15.5)	(12.6;17.0)	(-3.6;17.0)	(6.5;8.9)	(7.9;10.9)	(-15.9;74.8)	(2.5;3.5)	(4.5;5.0)	(34.5;97.3)	(9.1;12.3)	(12.9;15.4)	(3.4;74.1)
			0/0/100					1/2/97			1/53/46			43/55/2			69/21/9			100/0/0			91/8/1
CB	16.3	15.4	-5.9	5	3	61.8	55.0	-11.1	23.6	23.0	-2.7	12.3	15.5	+25.9	4.8	9.1	+94.9	2.1	3.9	+75.4	6.9	12.9	+89.3
(n=6)	(16.0;16.6)	(14.9;15.8)	(-7.4;-4.5)	(2;6)	(2;3)	(60.5;63.0)	(53.1;56.8)	(-13.4;-8.7)	(22.9;24.4)	(21.9;24.2)	(-7.1;2.0)	(11.7;12.9)	(14.2;16.8)	(20.6;31.4)	(4.3;5.2)	(8.3;9.8)	(79.0;112.1)	(2.0;2.2)	(3.3;4.4)	(46.8;109.6)	(6.3;7.4)	(11.9;13.9)	(73.4;106.6)
			0/0/100					0/0/100			3/45/52			100/0/0			100/0/0			100/0/0			100/0/0
WM	18.3	17.3	-5.3	2	2	69.2	63.0	-8.9	28.4	27.1	-5.1	14.7	15.2	+4.1	6.3	9.8	+56.8	5.0	5.4	+16.1	11.3	15.1	+39.4
(n=3)	(18.1;18.5)	(17.2;17.5)	(-7.0;-3.5)	(2;3)	(2;3)	(67.7;70.6)	(61.5;64.5)	(-10.8;-7.0)	(26.0;30.7)	(24.2;30.0)	(-18.5;10.6)	(12.7;16.6)	(13.5;17.0)	(-9.8;20.2)	(4.6;7.9)	(7.8;11.7)	(16.9;110.4)	(3.4;6.7)	(5.0;5.7)	(-15.6;59.6)	(8.0;14.7)	12.8;17.4)	(8.1;79.7)
			0/0/100					0/0/100			13/34/53			35/56/9			96/4/0			43/52/5			89/11/0

The number of games per testing period (separated by 4-5 months, see Methods, Period 1 and 2) are displayed as mean (range). Mean values (90% confidence limits), mean percentage changes (90% confidence limits) and chance for greater/similar/lower values in the amount of distance covered below 60% maximal aerobic speed (dist 0-60% MAS, m·min^{-1}), distance covered from 61 to 80% MAS (dist 61-80% MAS, m·min^{-1}), distance covered from 101% of MAS to 30% anaerobic speed reserve (dist 101-30% ASR, m·min^{-1}), distance covered above 31% ASR (dist >31% ASR, m·min^{-1}) and distance covered above 100% MAS (dist >100% MAS, m·min^{-1}) for players showing substantial decrements in maximal sprinting speed (MSS, km.h^{-1}) and peak incremental speed during the Vam-Eval test ($V_{vam\text{-}Eval}$, km.h^{-1}) over two consecutive testing periods. FB: full-backs, CB: centre-backs, MD: midfielders, WM: wide-midfielders and S: strikers. Note that the present results related to first half data only.

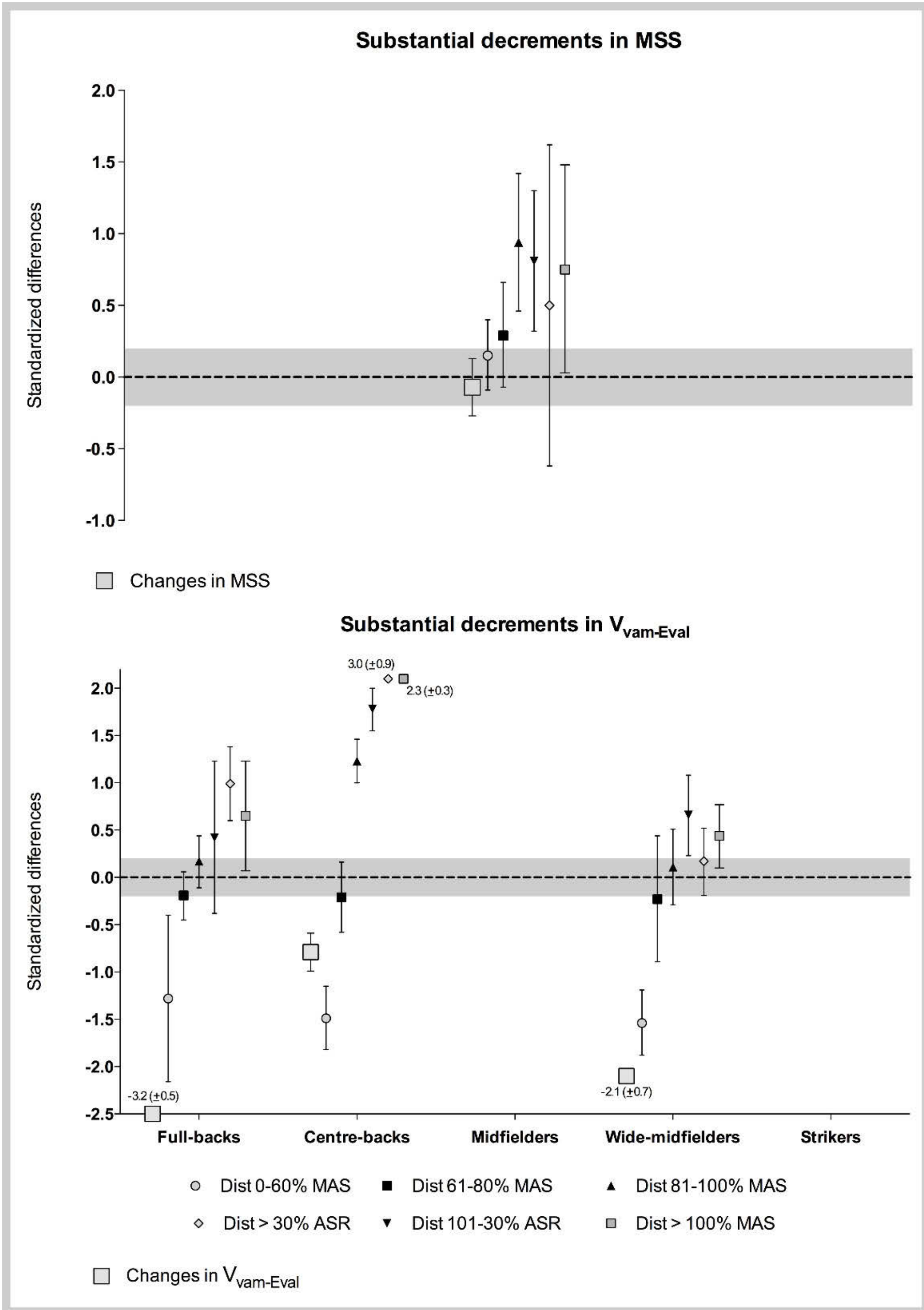

Figure 9. Standardised changes in physical capacities (Maximal sprinting speed, MSS, upper panel, or peak running velocity during the incremental test, $V_{vam\text{-}Eval}$, lower panel) and associated changes in relative match running performance variables (distance covered below 60% maximal aerobic speed (dist 0-60% MAS), distance covered from 61 to 80% MAS (dist 61-80% MAS), distance covered from 101% of MAS to 30% anaerobic speed reserve (dist 101-30% ASR), distance covered above 31% ASR (dist > 31% ASR) and distance covered above 100% MAS (dist > 100% MAS)) for players showing a substantial decrease in a given physical capacity over two consecutive testing periods. Note that the present results related to first half data only.

DISCUSSION

In this study we examined for the first time the effect of changes in physical capacity (i.e., MSS and MAS) on match running performance in highly-trained soccer players. The main results were: 1) the changes in absolute match running activities following an increased performance in MSS or MAS were either non-substantial or of lower magnitude, which in turn, lead to a lower match running activities when considering relative thresholds; and, 2) the changes in absolute match running activities were either unchanged or increased substantially in response to a reduced performance in MSS or MAS, which in turn, lead to greater match running activities when considering relative thresholds.

For the aim of the present study, focusing only on players showing either substantial improvements or decrements in physical performance was required to examine the respective impact of changes in physical capacity on match running performance. In these specific player-groups, the improvement in MSS and MAS were 6% (range: 3.4−11.7) and 9% (range: 5.1−21.5%), respectively (Table 3), which are similar to what has been reported in previous longitudinal studies (Helgerud, Engen, Wisløff, & Hoff, 2001; Impellizzeri et al., 2006). Caution should be taken when comparing the present results to these previous studies, as these previous studies included specific high intensity training interventions that were designed with the aim to improve physical capacity beyond normal training. In contrast, no additional training interventions (beyond normal training) were provided to the youth players in the present study. It is possible that some of the increases in physical capacity observed during the observation periods in this study were due to maturation.

Indeed, while adult players tend to show either stable or small decreases in physical performance over a competitive season (Caldwell & Peters, 2009; Casajus, 2001) it is common for young players show comparatively greater increases in performance during the same period (Buchheit et al., 2010a; Mendez-Villanueva, Buchheit, Kuitunen, et al., 2011; Strøyer, Hansen, & Klausen, 2004). These increases in younger players are likely related to their greater trainability (Ford et al., 2011) and growth and maturation-related effects (Malina, 1994).

The first finding of the present study is that changes in absolute match running performance measures in response to increased MSS and MAS were either non-substantial or of lower magnitude than the changes observed in the MSS and MAS. These findings suggest that improvements in physical fitness do not directly translate into similar improvements in match running performance. Interestingly however, the changes in match running performance tended to be of greater magnitude following substantial increases in MAS than MSS (e.g., FB: ES ranging from 0.0 to 1.5 for all performance variables following increases in MAS v -0.2 to 0.6 for MSS; Figure 6). Whilst these observations suggest that changes in MAS might be a greater determinant of match running performance than MSS but they also confirm that changes in physical fitness *per se* may not directly underpin changes in match running performance (Buchheit et al., 2015; Buchheit et al., 2010a; Buchheit, Mendez-villanueva, Simpson, & Bourdon, 2010b; Carling, Espie, Le Gall, Bloomfield, & Jullien, 2010; Mendez-Villanueva, Buchheit, Simpson, & Bourdon, 2013; Mendez-Villanueva, Buchheit, Simpson, Peltola, & Bourdon, 2011a). These observations agree with Carling (2013) who recently suggested that technical abilities of players, along with the tactical approaches adopted and other contextual factors such as the level of opponent, environment and score line may have a greater influence in match running activities than a player's fitness level.

An important finding from the present study was that the players with an increased physical capacity showed either unchanged or decreased match activity profile when relative thresholds were considered (Figure 7). These observations support recent findings suggesting that rather than increasing match running performance (i.e. covering greater distance and higher speeds during matches), increases in physical capacities likely allow for a decreased relative load during games (Mendez-Villanueva, Buchheit, Simpson, & Bourdon, 2013). Although not investigated in the present investigation, it may be that that a reduced relative activity profile may translate to improved fatigue resistance during matches and result in improved technical proficiency (Rampinini, Impellizzeri, Castagna, Azzalin, Ferrari Bravo, et al., 2008), with fitter players exercising at a lower internal intensity. Future studies should examine this hypothesis.

The present results showed that the magnitude of effect for the changes in fitness on the match running performance varied considerably between positions, with the FB, WM and S having their match running performance influenced to a greater extent by increases in fitness than the MD and CB. This is likely explained by the tactical positioning of both CB and MD, where they usually play within a relatively limited pitch area during games. It may be the position-specific tactical demands to remain within a constrained pitch area during games may limit the match running activity profile for both of these positions. It is likely that since these players do not increase match running activity despite increasing their fitness level that their relative match intensity decreases, which may have a positive effect on decision making, passing ability or an increased ability to cope with fatigue development during the end of the game. For example, we observed a moderate increase in MAS in the CB, but this was not associated with changes in absolute running performance. However, these changes were associated with a moderate-to-large decrease in relative match running intensity.

The changes in several match running performance measures also appeared to be position-dependent. For example, the strikers that had the greatest changes in absolute sprinting distance (large-to-very large increase) following moderate improvements in MSS and MAS. As discussed previously, these position-specific changes are likely related to the playing area each player works within during games. Because larger areas likely allow the greater high-speed activities and sprinting (Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011), the fact that attacking players show more improvements in speed-related match running performance was expected. Moreover, since each player's positioning in the pitch during matches is usually determined by the team's tactics or playing system and need to keep the team structure of shape during match – it is more likely that these factors affect match activity profile rather than changes in physical capacity. Collectively, these results support that technical and tactical factors have a large influence on physical activity during match play. These findings also suggest that whilst improving fitness may assist players cope with the physical requirements of match play, it may not necessarily translate into greater match running performance. Future studies should examine if the increases in fitness translate to technical proficiency (e.g. improve passing success or decision making) or influences recovery profiles from match play. Future studies could also determine the appropriate (i.e., high enough) fitness levels required for successful game participation with specific reference to players in different position-specific demands.

The second important finding of the present study is that absolute match running performances were either unchanged or increased, when the players' fitness capacities were decreased. Whilst it is logical to expect that decreased fitness would translate to decreased match activity (i.e. distances travelled), these results suggest that fitness was probably not a limiting factor to player activity during matches. The present findings also demonstrated that reduced fitness capacities resulted in an increased relative game intensity, as evidenced by the moderate to very-large increase in relative match running performance (Figure 9). The relationship between relative intensity and match performance is likely complex, as it may impact both physical (Mendez-Villanueva et al., 2013) and technical (Rampinini, Impellizzeri, Castagna, Azzalin, Bravo, et al., 2008) outcomes during soccer match play. However while a reduced relative exercise intensity is likely beneficially for technical performance (Rampinini, Impellizzeri, Castagna, Azzalin, Bravo, et al., 2008), its impact on physical performance is not clear as a myriad of contextual factors (i.e. tactics, team formations, score line etc.) can affect a player's match running activity.

Similar to the group that had periods where their fitness levels were increased; there was also a large variation in between-positions responses in match running performance in the responses to decreased fitness. For example, the CB showed small-to-large increased absolute game running performance after decreases in MAS (and hence, large-to-very large increased relative exercise intensity), whilst the FB and WM both showed unchanged absolute game running performance (and hence, only small to moderate increase in relative exercise intensity). While in line with our initial hypothesis, these results show that changes in physical fitness and match running performance are not necessarily matched, and that playing positions can affect these relationships. Nevertheless, since all these changes were position-dependent, position-specific tactical plays may have influenced the present results. The small sample size of some of the positional groups, together with the fact that the magnitude of the decrease in physical performance was not similar between the groups (i.e., twice greater decrease in MAS for FB than in CB, Figure 8) may explain some of the 'unexpected' results (e.g., CB showing a greater increase in match relative performance than WM, despite more space available for these latter positions).

Limitations

Due to the applied nature of the research there are a few limitations that should be acknowledged. For example, there were only a limited number of players showing impaired physical performance between two testing sessions, and as a result not all playing positions could be examined for this response. Moreover, despite making considerable effort in constructing the research design, many of the following factors, i.e., injuries; training and game exposure; and training content, that can affect running performance during match play were not assessed during the study. Therefore, caution should be taken when interpreting the mechanisms of these responses as factors not measured in this study may have affected these outcome measures. It is also clear that coaches/support staff would prefer that the players improved their physical qualities, and this may explain the relatively low number of occurrences of reductions in fitness during the study period.

There are also limitations with the 1-Hz sampling rate of the GPS devices used in this study. While we acknowledged that these devices have limitations in measuring speeds and distances travelled during short high-intensity actions, and that there are now GPS devices that have higher sampling rates which provide more precise measures during these activities. Nevertheless, the devices used in the present study have previously been reported to have good reliability and validity when capturing high-speed running actions (Barbero Álvarez et al., 2010; Coutts & Duffield, 2010). Moreover, to overcome some of the limitations encountered with these devices, all players wore the same devices during each match. In the absence of a gold standard method, future studies should look to measure match-running performance with the most reliable and valid microtechnology devices. However, since the technology and software associated with these devices are regularly upgraded, it is important for longitudinal studies that the same devices, software and data treatment systems are used throughout.

Another limitation is related to the lack of technical/tactical analyses. Since both these factors have been suggested as important contextual factors that can influence activity profiles during matches (Carling & Dupont, 2011a), the absence of this information limits a comprehensive examination of the effect of changes in fitness on match running performance.

A further limitation to the study is not analyzing the interaction between internal (i.e., heart rate) and external training loads during match play. Current literature suggests the integration of internal response (i.e., heart rate) may provide additional information towards changes in external work towards players' fatigue and movement economy during match play (Akubat, Barrett, & Abt, 2014; Carling, 2013; Kempton & Coutts, 2014). Therefore, additional analysis of the internal loads during match play are required to better characterize the impact these factors may have on exercise loads.

Conclusions and Practical Implications

In this study we aimed at investigating the impact of changes in physical capacities (i.e., MSS and MAS) on match running performance and exercise intensity in highly trained young soccer players. The present data provides further evidence showing that contextual factors such as playing position and tactical strategies constrain the match activity profile of football players, and that the effect of fitness per se on match running performance and exercise intensity is not as clear as previously suggested (Helgerud, Engen, Wisloff, & Hoff, 2001). In particular, based on the complexity of this relationship, the present results highlight the importance of delivering training interventions that concurrently develop position specific technical, tactical and physical qualities in young players.

Based on the present findings, it is difficult to provide specific recommendations on the direct value of physical fitness for improved match performance in young soccer players. Whilst previous studies have shown that players of higher playing standards have improved physical characteristics compared to players from lower standards of competition (Mohr et al., 2003), the benefit of improved fitness characteristics in high standard soccer players is less clear. Nonetheless, the present results confirm the importance of developing positioning-specific training strategies (Di Salvo et al., 2010). For instance, acceleration type work may benefit each position, in contrast improving MSS may have a greater impact on sprint activity as a consequence of the greater space available. Regardless of these recommendations, players are required to develop minimum levels of physical qualities to cope with the requirements of match play that allow them to meet the tactical and technical requirements to meet the team objectives. Future studies should examine the minimum requirements of physical fitness required to compete at specific levels of competitions. Identifying minimum standards of fitness for youth players may be more beneficial for guiding training requirements in developing players. Regardless of this, the influence of factors such as biological age, maturation status and trainability should also be considered when developing specific training programs for youth footballers. On the basis of the present results, it appears that changes in fitness qualities do not affect the match running performance, but it does appear that improving aerobic fitness can reduce the relative load and may help players cope better with match fatigue. Future studies should directly examine this suggestion.

CHAPTER FOUR

Thesis Summary

This thesis examined previously unknown relationships between changes in physical capacities and match running performance in young elite soccer players. In agreement with the original hypothesis, the present results showed that improvements in physical fitness performances are not systematically associated with comparable and concurrent changes in match physical performance.

These findings in this thesis provide further evidence suggesting that contextual factors such as playing position and tactical strategies constrain the match activity profile of football players more than fitness levels of players. Moreover, the present highlights also show that the independent effect of fitness on match running performance and exercise intensity during matches is not as clear as previously suggested (Helgerud, Engen, et al., 2001). Based on the present findings it is difficult to provide precise recommendations on the value of physical fitness qualities for improved match running performance. Nonetheless, the present results confirm the importance of developing positioning-specific training strategies that are appropriate to the age of athletes and the technical and tactical abilities of young soccer players.

Directions for Future Research

To expand upon the findings of this thesis, and to develop a greater understanding on the importance of fitness and match running performance measures in youth soccer, it is recommended that further research investigates the following:

- Directly assess the effect of changes on fitness on match-related fatigue by assessing concurrent changes in internal (e.g. heart rate) and external load (e.g. match activity measures) during match play.

- Use a multi-level mixed-modelling approach to assess the changes in fitness qualities on match running performance whilst accounting for influences of playing position, relative age, maturation status, level of opponent ability and other confounding factors that have been shown to influence match running performance.

- Examine the effect of changes in fitness qualities on technical skill or tactical approaches (i.e. field positioning, coordination with team mates etc.)

- Determine the relative importance of physical capacities, technical skill or tactical abilities for match performance in youth soccer players.

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