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Analysis of match and training performance in soccer using Global Positioning System technology

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A mio nonno

La sua guida e la sua presenza sono stati da sempre un supporto fondamentale. Perderlo a più di 1500 kilometri di distanza mi ha insegnato a dare valore alle cose che faccio, a dare importanza al tempo che passa inesorabile.

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Abstract

It generally accepted that soccer is one of the most popular sports in the world. Thanks to technology development, a progressively increasing in studies about external load monitoring in soccer match and training were published. Currently, several are the systems available to simultaneously analyze movement patterns of many players during a soccer match, including video-based time motion analysis equipment and global positioning system (GPS) devices. However, the use of one of the first two methods depends on various factors linked to the strengths and weaknesses of each methodologies. As far as concern GPS technology, it has been demonstrated that GPS devices are reliable instruments for monitoring the true metabolic demands during intermittent or high-intensity exercises such as soccer activities. However, there are several concerns about the use of GPS device to assess the very high-speed bouts, short sprints and/or movements with many changes of direction, even more when the sample rate of the GPS device is low. Different studies have shown that reliability of GPS devices gradually decreases in relation to increasing number of changes of directions and accelerations and to reducing running distance. Thus, first aim of this thesis was to investigate the validity and accuracy of GPS technology with a sampling rate ≧10Hz in order to evaluate if it could produce better information on brief activities speed during short shuttle runs.

Supporting by GPS technology, categories of movement described in relation to speed, acceleration or power thresholds, difference between playing position, analysis of fatigue during the match and physical demand in different soccer population (i.e adult versus young) have been analyzed during the training or game by researchers to better understand the workload imposed. Results obtained, in adult male players during a soccer match, identified in the high-intensity distance covered an important indicators of match physical performance.

Instead, in youth players most information is available for players between 12 and 17 yr of age but, for very young players (<11 yr of age), data describing the activity profile during match play are limited and thus a less clear picture of the movement demands of these developing players is evident.

Contrarily, information on match analysis about women's soccer is relatively few and more confused if compared to those of men. Indeed, so far, there is not universally agreement upon standard velocity thresholds utilized to quantify the distances covered in different locomotor activities, especially for high-speed running and sprinting. However, just recently some studies have presented common recommendation that are now being adopted.

Finally, it has been demonstrated that GPS technology could help to better evaluate the workload imposed by specific soccer training. In the last years, the methodology in soccer is changing and it became more difficult to check and program training in order to prevent injury. Not enough time is spent on physical conditioning without ball. Commonly, several technical and tactical exercises are considered the main activities during the soccer. The "modern" problem could be monitoring the global training load imposed from these type of training modalities. In this contest the new available technologies could help coaches and sport scientists to better assessed the soccer training workload. Unfortunately, few studies investigated the relationship between GPS data and muscle fatigue after soccer-specific training sessions, and to our knowledge no data are available about the muscle impairments after different soccer training modalities and their relationship with external workload calculated using GPS devises.

Therefore, the aims of this thesis were to describe the use of GPS technology in soccer. Four studies are developed in which the purposes were: 1) to evaluate the accuracy and inter-unit variability of a GPS device with a sampling rate of 20Hz for measuring mean and speed of shuttle runs; 2) to characterize match running performance of very young soccer players and evaluate the relationship between these data and physical capacities and technical skills; 3) to examine high-intensity distance covered during matches by elite female soccer players using different velocity thresholds and 4) to compare the decay in muscle performance after soccer-specific aerobic and traditional interval running training session.

Introduction and Overview

Soccer is considered the most popular sport in the world (Bangsbo, 1994). Thanks to its popularity, the scientists interest in the field increased, especially, as far as it concerned match performance and training.

Studying the literature, it is clear that soccer requires a high level of technical abilities as well as optimal physical skills (Bangsbo, 1994, Stolen et al., 2005). Thus, a soccer player tasks' are not only handle the ball and kick on goal but also jogging, running and sprinting for ninety minutes and over (Bangsbo et al., 1991; Mohr et al., 2003; Weston et al., 2007). As results of match analysis studies, during a male professional soccer match, repeated short high-intensity actions with brief recovery periods and a total of about 10-13 km cover distance are requires to the participants (Spenser et al., 2005, Bradley et al., 2009; Di Salvo et al., 2009).

From a physiological point of view, the combination of a relatively extensive game duration and the high-intensity intermittent nature of match play implies an enhanced in the aerobic energy system in order to achieve the game endurance requirements (Hoff et al., 2002, Iaia et al., 2009, Impellizzeri et al., 2006). However, an anaerobic energy component is necessary to perform the repeated high-intensity actions (Rahnama et al., 2003, Buchheit et al., 2010b, Buchheit et al., 2010a). The maximal aerobic power ($V'O_{2max}$) in male soccer players is between 50 $mL\cdot kg^{-1}\cdot min^{-1}$ and 75 $mL\cdot kg^{-1}\cdot min^{-1}$ and ~45 $mL\cdot kg^{-1}\cdot min^{-1}$ in women soccer players (Ingebrigtsen et al., 2011; Sirotic et al., 2007; Labsy et al., 2004) according to season period, location and competing level (Casajus 2001; Heller et al. 1992) (table 1.1). However, if $V'O_{2max}$ is a determinant for soccer performance it is still unclear. Despite some studies reported that the winning team had higher average of $\dot{V}O_{2max}$ than other teams (Apor et al., 1988), other suggested that $\dot{V}O_{2max}$ does not play a pivotal role in this sport.

Table 1.1 Anthropometric and physiological characteristics of male soccer players (Casajus, 2001).

Table V. Contd

Study	Level/country	n	Position	Anthropometry[a]		$\dot{V}O_{2max}$[a,b]			AT
				height (cm)	weight (kg)	L/min	mL/kg/min	mL/kg$^{0.75}$/min	(% $\dot{V}O_{2max}$)[b]
Drust et al.[70]	University/England	7		178.0 ± 5.0	72.2 ± 5.0	4.17	57.8 ± 4.0	168.5	
Ekblom[3]	Top team/Sweden						~61.0		
Faina et al.[60]	Amateur/Italy	17		178.5 ± 5.9	72.1 ± 8.0	4.62	64.1 ± 7.2	186.8	
	Professional/Italy	27		177.2 ± 4.5	74.4 ± 5.8	4.38	58.9 ± 6.1	173.0	
	world class/Italy	1					63.2		
Helgerud et al.[10]	Juniors/Norway	9				4.25 ± 1.9	58.1 ± 4.5	169.9 ± 9.6	82.4
	After training period	9				4.59 ± 1.4	64.3 ± 3.9	188.3 ± 10.6	86.3
	Division 1/Norway	21		183.9 ± 5.4	78.4 ± 7.4	4.73 ± 0.48	60.5 ± 4.8	178.4 ± 14.8	
	After training period	21		183.9 ± 5.4	78.4 ± 7.4	5.21 ± 0.52	65.7 ± 5.22	192.9 ± 19.4	
Heller et al.[71]	League/Czech	12		183.0 ± 3.5	75.6 ± 3.4	4.54	60.1 ± 2.8	177.2	79.4
	After season	12				4.48	59.3 ± 3.1	174.9	81.1
Hoff et al.[72]	Division 2/Norway[d]	8				4.63 ± 0.51	60.3 ± 3.3	178.6 ± 13.3	85.5
Hollmann et al.[59]	Nationals-78/Germany	17					62.0 ± 4.5		
Impellizzeri et al.[73]	Young/Italy	19		178.5 ± 4.8	70.2 ± 4.7	4.03	57.4 ± 4.0	166.2	
Leatt et al.[74]	U-16 elite/Canada	8		171.1 ± 4.3	62.7 ± 2.8	3.68 ± 0.43	59.0 ± 3.2	165.2	
	U-18 elite	9		175.8 ± 4.4	69.1 ± 3.4	3.99 ± 0.59	57.7 ± 6.8	166.5	
MacMillan et al.[75]	Youth team/Scotland	11		177.0 ± 6.4	70.6 ± 8.1	4.45 ± 0.37	63.4 ± 5.6	183.3 ± 13.2	
	After training period	11			70.2 ± 8.2	4.87 ± 0.45	69.8 ± 6.6	201.5 ± 16.2	
Matkovic et al.[76]	Division 1/Croatia	44		179.1 ± 5.9	77.5 ± 7.19	4.12 ± 0.64	52.1 ± 10.7	157.7	
Nowacki et al.[77]	Division 3/Germany	10					69.2 ± 7.8		
Puga et al.[78]	Division 1/Portugal	2	G	186.0	84.4	4.45	52.7	159.7	
		3	CB	185.3	75.9	4.16	54.8	161.7	
		2	FB	175.0	67.5	4.19	62.1	178.0	
		8	M	176.8	74.0	4.58	61.9	181.6	
		6	A	174.6	71.1	4.31	60.6	176.0	
Rahkila and Luthanen[79]	Senior/Finland	31		180.4 ± 4.3	76.0 ± 7.6	4.20 ± 0.30	56.0 ± 3.0	163.2	83.9
	U-18 plus U-17/Finland	25		178.6 ± 6.3	71.3 ± 6.8	4.00 ± 0.50	56.0 ± 4.0	163.0	85.7
	U-16/Finland	21		177.1 ± 7.4	66.7 ± 6.8	3.80 ± 0.40	58.0 ± 5.0	162.8	84.5
	U-15/Finland	29		174.7 ± 5.1	62.5 ± 6.5	3.60 ± 0.40	57.0 ± 5.0	162.0	86.0
Rhodes et al.[80]	Olympic/Canada	16		177.3 ± 6.5	72.6 ± 6.2	4.20 ± 0.40	58.7 ± 4.1	168.9	
Strøyer et al.[37]	EbP/Danish	9		154.1 ± 8.2	42.5 ± 7.2	2.47 ± 0.28	58.6 ± 5.0	148.2	
	EeP/Danish	7		172.2 ± 6.1	57.5 ± 7.2	3.59 ± 0.44	63.7 ± 8.5	172.1	
Vanderford et al.[81]	U-14/US	20		163.9 ± 0.4	49.9 ± 0.4	2.64	52.9 ± 1.2	140.6	65.9 ± 1.4

Moreover, Reilly et al. (2000) have been reported that there is a threshold (i.e. $\dot{V}O2max$ >60 mL•kg^{-1}•min^{-1}) representing a physiological attribute for successing in elite soccer. Physical preparation in elite players has become indispensable for professional soccer considering the high fitness level required to cope the continuous intermittent increasing in energy demands during a match-play (Iaia, et al., 2009). In the modern match-play analysis, the crucial element seems to be the high-intensity actions concerned sprint, acceleration, deceleration and distance covered at high-speed running (Carling et al., 2008).

In order to evaluate the physical demand of soccer match concerned the total work, but also the high-intensities activities, different technologies have been developed during the last decades.

GPS Technology and its application in soccer

In the past, it was difficult clearly measure and quantify the player movement demands because this operation was time-consuming and operator dependent (Roberts et al., 2006).

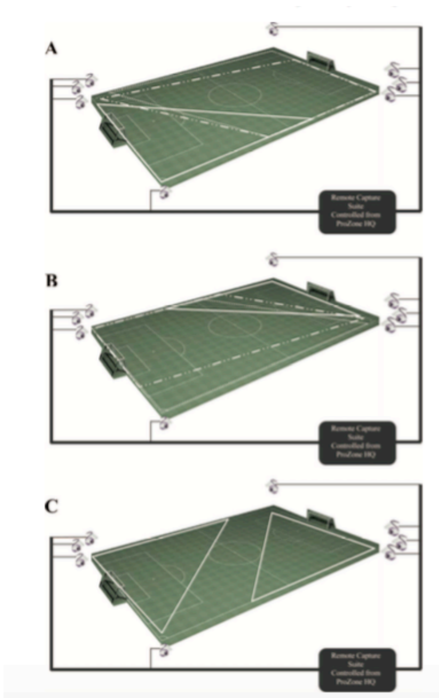

Figure 2.1 The ProZone1 capture system uses eight colour cameras that cover the entire pitch from all four corners of the stadium: (A) cameras 1–3 positioned in corner 1; (B) cameras 4–6 positioned in corner 2; (C) cameras 7 and 8 positioned opposite one another (Bradley et al., 2009).

Recent technological development improved movement patterns analysis of soccer players. This analysis can be performed manually and/or computer-assisted by video-based time motion systems (**figure 2.1**) and global positioning system (GPS) devices (Carlin et al., 2008; Dobson et al., 2007).

The GPS technology was invented by the physics Nobel prize awarded Isidor Rabi in 1944. Hydrogen atom was used by Isidor Rabi to invent the magnetic resonance method (Aughey et al., 2011). Due to this new method, it has been possible to create the atomic clocks, the precise timepieces representing the basis of satellite navigation (Aughey, 2011).

The US Department of Defense invested funds GPS system for military use and navigation purposes. They sent 32 operational satellites in orbit around earth. Each satellite is equipped with an atomic clock (Larsson, 2003). Each length of time and GPS signal receiver connects to the satellites that synchronizes its clock with the atomic clock in the satellite. In order to calculate the distance from satellite the signal travel time is multiplied with the speed of light. By calculating the distance to at least three satellites, the exact position (altitude, latitude and longitude) can be trigonometrically determined (**figure 2.2**). Another one satellite is necessary to calculate the 4th variable: the time. In 1991 the US Department of Defense deliberate a selective availability with a system error inside, and only in 1999 this error was removed (Larsson, 2003).

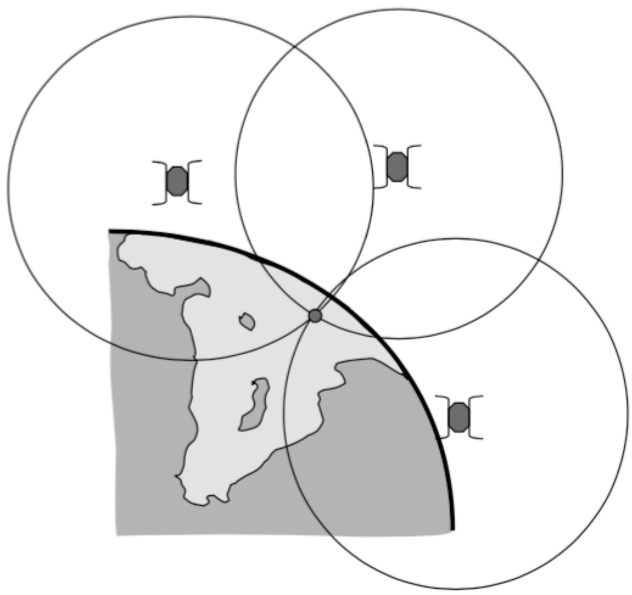

Figure 2.2 *An example how to determine position by the use of GPS. The distance to at least three satellites is required. (Larsson, 2003).*

Recently, GPS technology has been extensively used for collecting and analyzing movement data in order to evaluate the most important physical actions performed by players of different sports (Aughey & Fallon, 2009; Barbero-Álvarez et al., 2010; Coutts et al., 2010). Several studies demonstrated that GPS devices are accurate enough for monitoring the real demands of intermittent exercise and calculate then the mean metabolic power during high-intensity activities (Rampinini et al., 2015). However, there are several concerns related to the use of GPS devices to measure very high-speed bouts and it has been shown that the sample rate of the devices, as well as speed, effort duration and nature of the task affect the accuracy (Coutts & Duffield, 2010). Moreover, other studies have shown that reliability of GPS devices gradually decreases in relation to increasing number of changes of directions and accelerations and to reducing running distance (Castellano et al., 2011; Jennings et al., 2010; Portas et al., 2010). The authors investigated the validity and accuracy of GPS technology with a sampling rate of 1 Hz, 5 Hz or at the most of 10 Hz and they showed that the sampling rate is an important parameter to improve the measure exactitude in short high-intensity activities. Nagahara et al. (2016) showed that concurrent validity for obtaining mechanical properties during straight-line sprint acceleration was better using 20 Hz GPS device than that obtained from 5 Hz GPS device, even if GPS units are not recommended to measure the sprint acceleration mechanical properties.

Match performance evaluation by GPS technology

In the last decades GPS technology has been used to better understand and describe the physical demands of soccer match-play, including analysis of: (i) the categories of movement described in relation to speed or acceleration or power thresholds (Bradley et al., 2009); (ii) differences between playing position (Rampinini et al., 2007); fatigue during matches (Mohr et al., 2003); physical demand in different soccer population, such as adult versus young (Buchheit et al., 2010) or male versus female (Bradley et al., 2014).

Professional male soccer players cover about 8 - 13km during the course of a match (Di Salvo et al., 2009), in relation to playing position and/or to the different moment of the season (Rampinini et al., 2007). Total distance run is not the only parameter utilize to analyze the performance during the match. Movement activities are generally coded according to their intensity and speed thresholds: standing, walking (0–0.6 $km \cdot h^{-1}$), jogging (7.2–14.3 $km \cdot h^{-1}$), running (14.4-19.7 $km \cdot h^{-1}$), high-speed running (19.8–25.1 $km \cdot h^{-1}$) and sprinting (> 25.1 $km \cdot h^{-1}$) (Bradley et al., 2009). In a soccer match, almost of the activities are performed at low-intensity, even though high-speed running or high-intensity distance are considered important indicators for match physical performance (Mohr et al., 2003). It may possible that differences in total distance between levels of play or in different tactical role of players in both female and male players are present as consequence to difference training program leading to different physiological changes (Di Salvo et al., 2009).

Table 3.1 Typical speed thresholds used to measure high-intensity distance in soccer match.

Study	High-intensity thresholds (km·h^{-1})	Mean HID (m)	Standard Deviation.
Mohr, *et al.*, (2003)	>15	2430	140
Rampinini, *et al.*, (2007)	>14.4	2530	532
Bradley, *et al.*, (2009)	>14.4	2492	625
Barros, *et al.*, (2007)	>19	1128	-
Di Salvo, *et al.*, (2007)	>19.8	930	161

As for high-intensity zone, there is no consensus about speed thresholds used and tis topic is still debated in literature. The different values proposed are the following: 13 km·h^{-1} (Mallo, Navarro et al., 2007), 14.4 km·h^{-1} (Rampinini et al., 2007a; Rampinini et al., 2007b), 15 km·h^{-1} (Andersson et al., 2008; Bangsbo et al., 1991), 18.1 km·h^{-1} (Castagna & D'Ottavio, 2001), 19.1 km·h^{-1} (Di Salvo et al., 2007), and 19.8 km·h^{-1} (Weston et al., 2007) (**table 3.1**). However, the most used speed threshold to identify high-intensity/speed running distance in male soccer players seems to be 15 km·h^{-1} (Abt et al, 2009; Andersson et al., 2008; Bangsbo et al., 1991). Abt et al., in 2009, showed that this speed corresponded at the second ventilator threshold (VT_2) obtained during and incremental treadmill test in elite male soccer players.

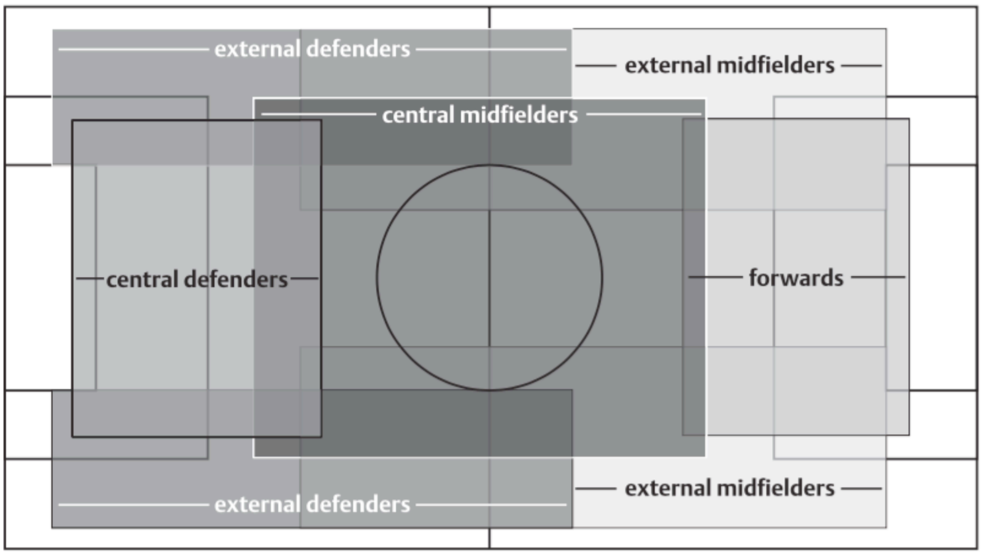

Figure 3.1 Techno-tactical assignment to positional roles based on match-analyses (Di Salvo et al., 2007).

However, to better describe the physiological load imposed on top-level soccer players it is necessary to evaluate the externa load per their positional role (**figure 3.1**). Di Salvo et al. (2007) found a mean total distance of ~11400 m in 300 elite Spanish soccer players and they showed that both central and external midfielders covered a significantly greater distance than both defender and forward groups. Central defenders were found to spend significantly more time and cover a longer distance in low-speed categories (0 – 11 $km \cdot h^{-1}$) than any other playing position. The highest percentage of time and the greatest distance in high-speed running and sprinting were covered by external midfield players. In agreement with the findings of Di Salvo et al. (2007), Bradley et al. (2009) showed that in England wide (3138 and 11,535 m) and central midfielders (2825 and 11,450 m) soccer players covered more high-intensity running and total distance than full-backs (2605 and 10,710 m), attackers (2341 and 10,314 m), and central defenders (1834 and 9885 m). Furthermore, wide midfielders, full-backs, and attackers covered a greater distance in sprinting (346, 287, and 264 m, respectively) than central midfielders (204 m) and central defenders (152 m).

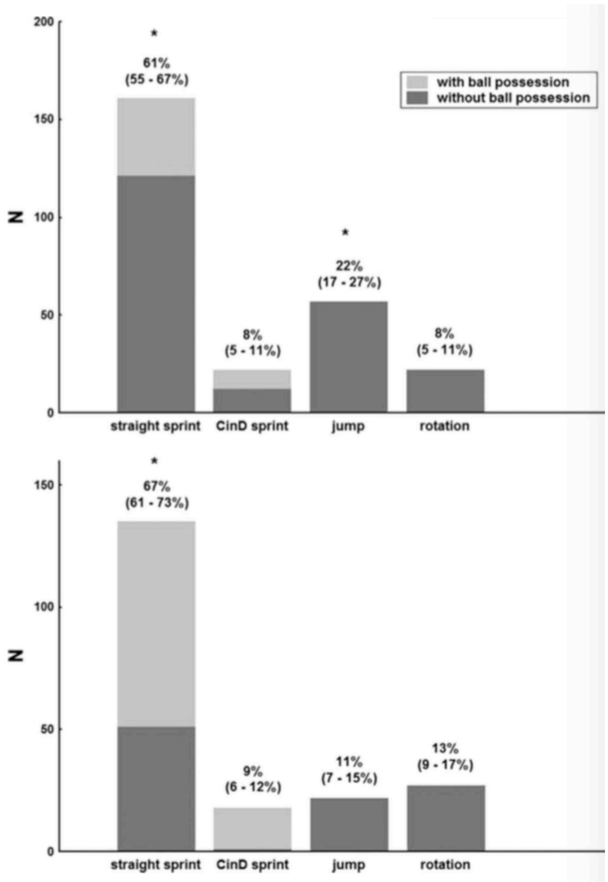

Figure 3.2 The frequency of powerful actions with and without ball possession in goal situations for the scoring (top) and the assisting player (bottom). Data as absolute and relative frequencies (with 95% confidence intervals). *1⁄4significantly different to all other categories. CinD 1⁄4 change-in-direction (Faude et al., 2012).

The sprint activities consist only on 1 to 12% of the total distance covered in match play (Di Salvo et al., 2010). Although this percentage is very low the sprint activities are decisive in soccer. Faude et al. (2012) showed that in 83% of all goals (298 out of 360 goals) during the second half of the season 2007/08 in the German Bundesliga at least one powerful action of the scoring or assisting player was observed. In this study, straight sprinting was the most frequent powerful action prior to scoring for the scoring as well as for the assisting player (**figure 3.2**).

Recently, the researchers have focused their attention to accelerations and decelerations in addition to the distance covered at different speed threshold. Indeed, these findings underling the importance of ability to accelerate and reach maximal speeds quickly in soccer (Varley & Aughey, 2013). A total number of ~91 accelerations was reported from Ingebrigsten et al. (2015) for Norwegian soccer players, with a higher number during first versus second half (47 vs 44). Previously Bradley et al. (2010) found about 30% more accelerations in English premier league than in Norwegian.

Table 3.2 Number of effeorts for high-intensity movemens in the first and second half and as a match total according to playing positions (Varley & Aughey, 2013).

Match Activity	Half	Central Defender	Wide Defender	Central Midfielder	Wide Midfielder	Forward
high-velocity running	1st half	$53 \pm 15^{a,c}$	81 ± 10^{b}	63 ± 25	76 ± 17	66 ± 20
	2nd half	52 ± 16^{a}	76 ± 16	62 ± 20	$65 \pm 17^{*}$	60 ± 13
	total	$104 \pm 28^{a,c}$	156 ± 22^{b}	125 ± 41	141 ± 31^{d}	127 ± 23
sprinting	1st half	$2 \pm 2^{a,c,d}$	$7 \pm 3^{b,c}$	$2 \pm 2^{c,d}$	5 ± 3^{d}	7 ± 4
	2nd half	$3 \pm 2^{a,d}$	$5 \pm 3^{b,c}$	2 ± 2^{d}	$3 \pm 2^{*,d}$	7 ± 4
	total	$5 \pm 3^{a,c,d}$	$12 \pm 5^{b,c}$	$4 \pm 4^{c,d}$	8 ± 4^{d}	14 ± 6
maximal acceleration	1st half	28 ± 10^{a}	$47 \pm 7^{b,c,d}$	30 ± 13	35 ± 10	34 ± 12
	2nd half	28 ± 11^{a}	$43 \pm 10^{b,c,}$	30 ± 10	$30 \pm 11^{*}$	34 ± 10
	total	56 ± 18^{a}	$90 \pm 15^{b,c,d}$	60 ± 20	65 ± 18	69 ± 19
high-intensity activity	1st half	$74 \pm 21^{a,c}$	$114 \pm 10^{b,d}$	84 ± 32	100 ± 22	90 ± 27
	2nd half	71 ± 21^{a}	$106 \pm 21^{b,c,d}$	83 ± 24	$86 \pm 23^{*}$	84 ± 24
	Total	$145 \pm 38^{a,c}$	$220 \pm 29^{b,d}$	167 ± 51	186 ± 41	173 ± 33
low-velocity acceleration	1st half	21 ± 7^{a}	$33 \pm 7^{b,c,d}$	21 ± 10	24 ± 8	22 ± 9
	2nd half	19 ± 8^{a}	$31 \pm 9^{b,c}$	21 ± 8	21 ± 9	24 ± 8
	Total	40 ± 14^{a}	$64 \pm 13^{b,c,d}$	42 ± 14	45 ± 14	46 ± 15

All data is mean ± SD. ^{a}: significant difference vs. wide defender ($P < 0.05$), ^{b}: vs. central midfielder, ^{c}: vs. wide midfielder, ^{d}: vs. forward, *vs. 1st half

Considering the importance of sprint and acceleration/deceleration phase of running in soccer match, as for high-intensity distance, some authors have also evaluated the distribution of accelerations among players with different positions. Varley & Aughey (2013) analysed the acceleration profile in relation to playing position and they found that the number of maximal accelerations were homogenous across all positions, except for wide defenders. (**table 3.2**). The higher number of accelerations undertaken by these players may be due to their tactical role: wide defenders are used to perform both defensive and offensive phases resulting in constant back and forth movements. In this study the authors underlined that all positions performed significantly more acceleration than sprint efforts. In this contest accelerations and decelerations became essential elements describing physical demand of soccer. Indeed, a great metabolic load is imposed on players not only when player run at high speed but also every time acceleration is high, even when speed is low (Osgnach et al., 2010). Before the study of Osgnach et al. (2010), the only way to consider the physical load was to calculate the total distance, or distance in different speed categories or the number of acceleration and deceleration. The new metabolic approach allows to estimate the total energy expenditure not only in relation to speed but also taking into account accelerations and decelerations during the various phases of the match. This could be very important to better evaluate the training and match load imposed on soccer players.

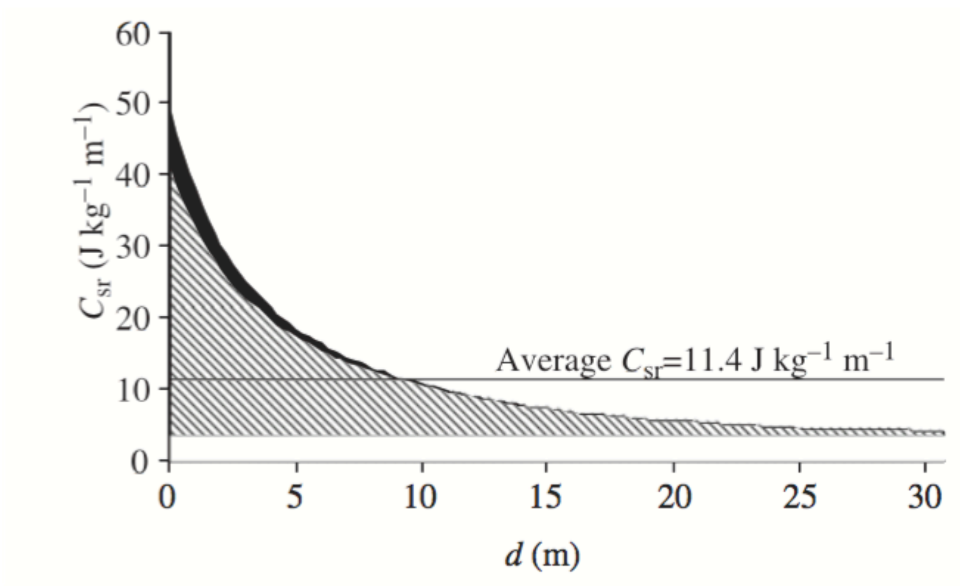

Figure 3.3 Energy cost of sprint running (Di Prampero et al., 2005).

The scientific literature reports a huge number of studies on the energetics and biomechanics of constant speed running, but to calculate the energy expenditure in a high intensity intermittent sport like soccer is need to estimate the correct energy expenditure including the accelerated (or decelerated) running. In fact, if we consider only the energetic cost at a constant speed the corresponded value is speed independent and it is ~3.6 J·kg^{-1}·m^{-1}, but during a sprint the instantaneous energetic cost attains a peak of about 50 J·kg^{-1}·m^{-1} immediately after the start; thereafter it declines progressively and it reaches the value for constant speed running on flat terrain after about 30 m (**figure 3.3**).

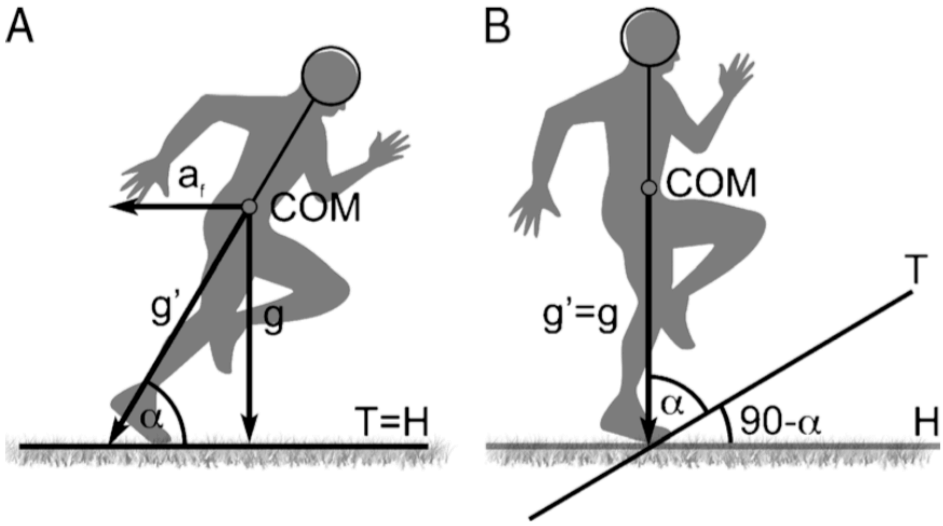

Figure 3.4 Simplified view example of the forces acting on a subject during accelerated running. The runner's body is represented by a segment of straight line. COM, center of mass; T, terrain; H, horizontal; g, acceleration of gravity; a_f, forward acceleration; g', vectorial sum of a_f and g. Accelerated running on flat terrain (A) is equivalent to constant speed uphill running (B) wherein the angle of the terrain T with the horizontal H (90-α) is such that the angle of the subject's body with the terrain (α) is unchanged. (Osgnach et al., 2010)

In 2005, Di Prampero et al. reported that accelerated running on a flat terrain is energetically equivalent to uphill running at constant speed up an equivalent slope, the upslope being dictated by the forward acceleration (**figure 3.4**).

In this way players that don't reach elevated speeds could cover the same distance at high intensity (with a metabolic power threshold) than players that play in a position in which it's possible to reach elevate speed. In **figure 3.5** it's possible to observe that players can reach the same metabolic power in two different way: 1) running at high speed with low acceleration or deceleration; 2) running at very low speed but with high acceleration or deceleration.

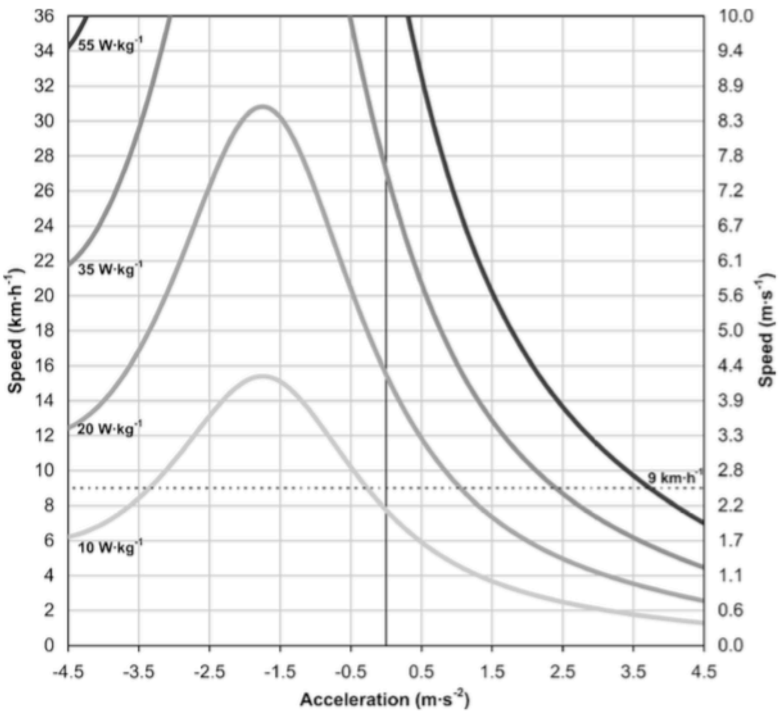

Figure 3.5 Isopower relationships calculated as function of speed (y-axis) and acceleration (x-axis) (Osgnach et al., 2010).

In order to consider the new metabolic approach proposed by Di Prampero et al. (2005) and Osgnach et al. (2010), the following five power categories are used: low power (from 0 to 10 $W \cdot kg^{-1}$), intermediate power (from 10 to 20 $W \cdot kg^{-1}$), high power (from 20 to 35 $W \cdot kg^{-1}$), elevated power (from 35 to 55 $W \cdot kg^{-1}$), and max power (>55 $W \cdot kg^{-1}$). Usually, 20 $W \cdot kg^{-1}$ is the metabolic power threshold utilized to describe high intensity in soccer because this value corresponds to a $V'O_2$ of approximately 57 $mL \cdot kg^{-1} \cdot min^{-1}$, very close to the mean $V'O_{2max}$ of elite soccer players. Since no scientific data exist that try to explain the meaning of the threshold used to create categories in match analysis, to use a parameter with this physiological meaning could be a good approach to individualize and to create specific-soccer thresholds. **Figure 3.6A** shows the total time distance expressed as percentage of total distance covered in different speed zone, **figure 3.6B** shows the total time distance expressed as percentage of total distance covered and energy expressed as percentage of total energy in different metabolic power zone. High intensity distance covered by top-class players was approximately 18% of TD using a speed threshold of 16 km·h^{-1}, although they spent more than 42% of the total energy at high-power output (>20 W·kg^{-1}).

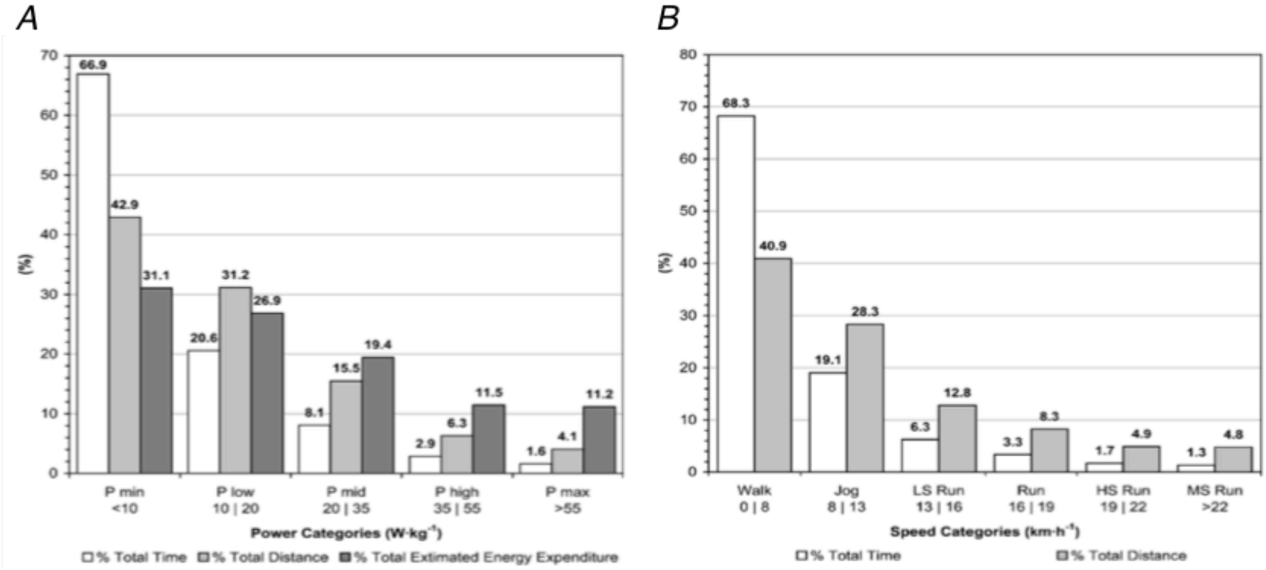

Figure 3.6 A) Time (T), Distance (D) and Energy expenditure (EEE) (%), during the entire match in each power category; B) T and D (%) during the entire match in each speed category (Osgnach et al., 2010).

Despite the metabolic power approach has significant advantages, it is not without limitations. First, the acceleration data per se have an inherent systematic error consequence of filtering and sampling rate (Castagna et al., 2016) especially due to the error of the instruments. Another limitation is the inability of the metabolic power model to estimate energy expenditure compared to a direct measure of energy expenditure measured using metabolimeter. In recent studies, Buglione & di Prampero (2013) as well as Stevens et al. (2015) found an overestimation of energy expenditure during constant velocity running and an underestimation during shuttle running, in a particular way when the distance to cover is very short and the speed is high. In another study of Buchheit et al. (2016) it has been shown that during soccer exercise with ball the energy expenditure estimated using metabolic power model was largely underestimated. Finally, Brown et al. (2016) showed that during steady state jogging and running the GPS derived estimation of energy expenditure was reasonably accurate, but during intermittent movement patterns (typical of soccer) there was a very large underestimation of energy expenditure (**figure 3.7**). Finally, some authors have raised doubt about the theoretical approach of the metabolic power method. As reported by Brown et al. (2016), there are different assumptions that may impact the validity of this approach, it is ascribed that: 1) by a biomechanical point an accelerated running is analogues to constant speed running up an incline. Moreover, no differences have been underlined including body inclination or the economy of accelerated and decelerated running between individuals; 2) in a runner the entire body mass is located proximally to the center of mass without disregards the discrete involvement of the upper and lower limbs; 3) changes of direction as well as air resistance must be considered during a running in flat or non-flat terrain (Brown et., 2016). However, at the moment metabolic power approach is the most utilized to estimate energy expenditure in high-intensity intermittent sports like soccer.

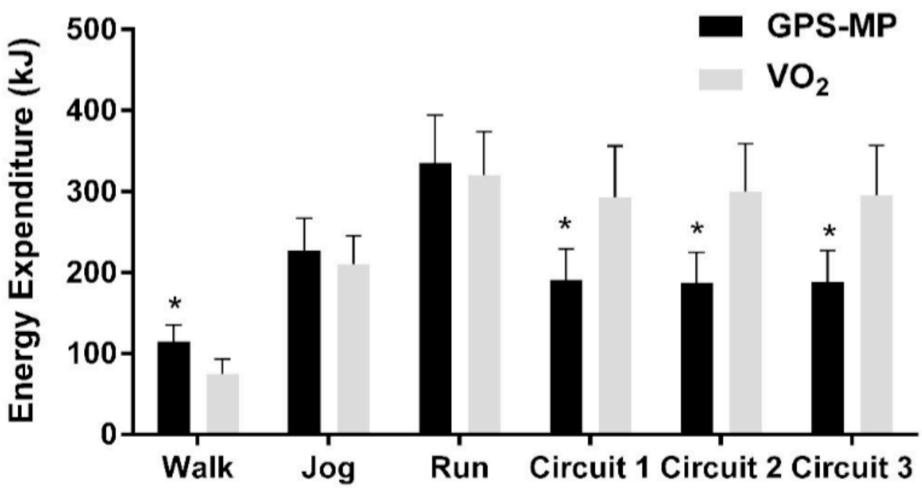

Figura 3.7 Comparison between GPS metabolic power (GPS-MP) estimates of energy expenditure (kJ) and indirect calorimetry (V'O_2) for each *15-minute* bout (*5-minute* exercise plus *10-minute* recovery) for exercise and field sport circuits. Data are Mean ± SD. * significan*t difference (p<0.01) (Brown et al., 2016).*

Female soccer players

In these last years, the women's match physical performance has received increasing attention because of an increase of women's soccer participation (Andersson et al, 2010; Mohr et al. 2008). The physiological loadings during matches seems to be similar across gender with a great engagement of the aerobic system, particularly during intense periods of a game (Bangsbo, 1994; Ekblom, 1986; Krustrup et al., 2010; Krustrup et al., 2003, 2005, 2006; Mohr et al., 2004). It has been shown that male players cover more distance in total and at higher speed thresholds, and in relation to playing position male full-backs, central and wide midfielders covered more distance in higher speed thresholds compared to their female counterparts. No differences were observed between attackers and central defenders. Gender differences were more pronounced at the higher speed thresholds than for the total distance covered in a match, but the high-intensity running speed threshold is usually set at > 15 $km \cdot h^{-1}$. Since women physical capabilities are lower than in men soccer players both in aerobic and anaerobic fitness test (Bradley et al., 2011; Bradley et al., 2012; Mujika et al., 2009; Rhodes & Mosher, 1992; Tamer et al., 1997), it is not surprising that elite female soccer players covered in matches 30% lower high-intensity running distance than their male counterparts (Krustrup et al., 2005; Mohr et al., 2008). Different studies analyzed the $V'O_{2max}$ in male and female soccer players and showed that the corresponded speed measured during treadmill test ($V'O_{2maxspeed}$) was significantly lower in female than in male (Ingebrigtsen et al., 2011; Sirotic et al., 2007; Labsy et al., 2004; Castagna et al., 2006). The reported values of $V'O_{2maxspeed}$ were about 17.5 $km \cdot h^{-1}$ in male and 14.5 $km \cdot h^{-1}$ in female soccer players. Aerobic fitness differences have been showed not only during treadmill test performed on laboratory but also during field-based intermittent test such as Yo-Yo Intermittent recovery test (Yo-Yo IRT) that is regarded as a good measure of aerobic-anaerobic indices widely used in team sport (Krustrup et al., 2003). A strong relationship has been shown between Yo-Yo IRT and VO_2maxspeed (Castagna et al., 2006) obtained on treadmill. While it is plentiful of data about elite male players during a Yo-Yo IRT1 (about 17.0 to 17.5 km·h^{-1}) (Krustrup et al., 2005; Sirotic et al., 2007), scarce are data about elite female players. However, it has been reported that from 1000 to 1380 m (Krustrup et al., 2005; Sirotic et al., 2007), the majority of female players achieved velocities of 15.0 to 15.5 km·h^{-1} with in elite female players that reached 16.0 to 16.5 km·h^{-1} (Bradley & Vescovi, 2015).

Different studies used 15 km·h^{-1} as speed threshold in male and female (**table 3.3**) soccer players (Krustrup et al., 2005; Mohr et al., 2008; Andersson et al., 2010; Andersson et al., 2008; Bangsbo et al., 1991), but given that female have lower physical capabilities it will be more appropriate to use a speed threshold with the same physiological meaning.

Table 3.3 Absolute and relative distances for high-intensity running in women's soccer matches (modified by Bradley & Vescovi, 2015).

		High-Speed or -Intensity Running		
Study	**Standard**	**Threshold (km/h)**	**Distance (m)**	**% total**
Andersson et al[2]	International senior	>15	1530	15.5
	Domestic senior	>15	1330	13.4
Bradley et al[3]	UEFA senior	>15	1358	12.6
	UEFA senior	>18	718	6.7
Krustrup et al[4]	Domestic senior	>15	1310	12.7
McCormack et al[48]	College	>13	1585	17.7
Mohr et al[17]	Top-class senior	>15	1680	16.3
	High-level senior	>15	1300	12.5
Vescovi[7]	Youth (U15)	15.5–20	458	6.6
	Youth (U16)	15.5–20	611	7.6
	Youth (U17)	15.5–20	658	7.7
Vescovi and Favero[1]	College	15.5–20	813	8.2

Abbreviation: UEFA, Union of European Football Associations.

The rationale for the choice to use this default speed threshold is originally based on an estimate of exercise intensity (soccer running) close to the $V'O_{2maxspeed}$ for males (Bangsbo, 1994; Greig et al., 2006). The reported values of $V'O_{2maxspeed}$ were about 17 km·h^{-1} in male and 14.5 km·h^{-1} in female soccer players. Considering these values, the speed threshold of 15 km·h^{-1} corresponds at 88% and 103% of $V'O_{2maxspeed}$, respectively.

Abt et al. (2009) assessed second ventilatory threshold in male soccer players and reported a speed threshold of 15 km·h^{-1}, showing that the speed that for female represent a value greater than their V'$O_{2maxspeed}$, for male represent only the transition between moderate- and high-intensity exercise (Esteve-Lanao et al., 2005; Lucıa et al., 2000). An athlete exercising at an intensity above this threshold will usually display an inability to sustain exercise (Davis, 1985; Wasserman, 1984), in male soccer players this speed is very close to 15 km·h^{-1} but for female the physiological meaning is totally different. The choice to use individual o specific threshold is an actual discussion topic and it have received increasing attention. Finally, Abt et al. (2009) suggested that the absolute high-intensity speed threshold of 15 km·h^{-1} is the most appropriate of the many absolute high-intensity speed thresholds used in male soccer players because there is a physiological meaning and because this is the most used in different studies to differentiate between levels of play in both female and male players, to analyse the physiological changes associated with the completion of a training program and to variations in stages of the competitive season and tactical role of players (Di Salvo et al., 2009). Thus, new studies on different speed threshold in female players are needed to understand the importance of high-intensity distance, to differentiate performance level, or to understand the development of fatigue during match.

Young soccer players

Most information about youth players are available for players between 12 and 17 years of age (Saward et al., 2016; Buchheit et al., 2010; Castagna et al., 2009; Castagna et al., 2010; Harley et al., 2010; Rebelo et al., 2014). The correct evaluation of the physical load imposed from match in young soccer players could help coaches to better comprise the talent in soccer (Saward et al., 2016) and it would have implications for the match performance, the design of the specific training programs, and the development of testing procedures (Carling et al., 2008). Try to understand an age-related change in match performance could be very important in order to acquire this information about talent identification. Analyzing the trend of match data in different studies (Harley et al., 2010; Pereira Da Silva et al., 2007; Buchheit et al., 2010; Mendez-Villanueva et al., 2013) it seems that there is an age-related increase of total distance covered during the match. In a particular way, Saward et al., in 2016, showed that total distance increased with age at a constant negative rate, which resulted in a plateau and subsequent decrease at 17.7 years. Previously, Buchheit et al., in 2010, found that match running performance was slightly affected by age (**figure 3.8**), but when match data are normalized for individual playing time, there was no difference in running performance between different age groups; significant differences in TD have been observed only for the youngest (U13) vs. the 3 oldest teams (U16, U17 and U18). In general, we can affirm that the total work (in terms of distance covered during match) is grater in older players than in younger ranged from 4356 ± 478 m in U9 players (Goto et al., 2015) to 8867 ± 859 m in U18 players (Buchheit et al., 2010).

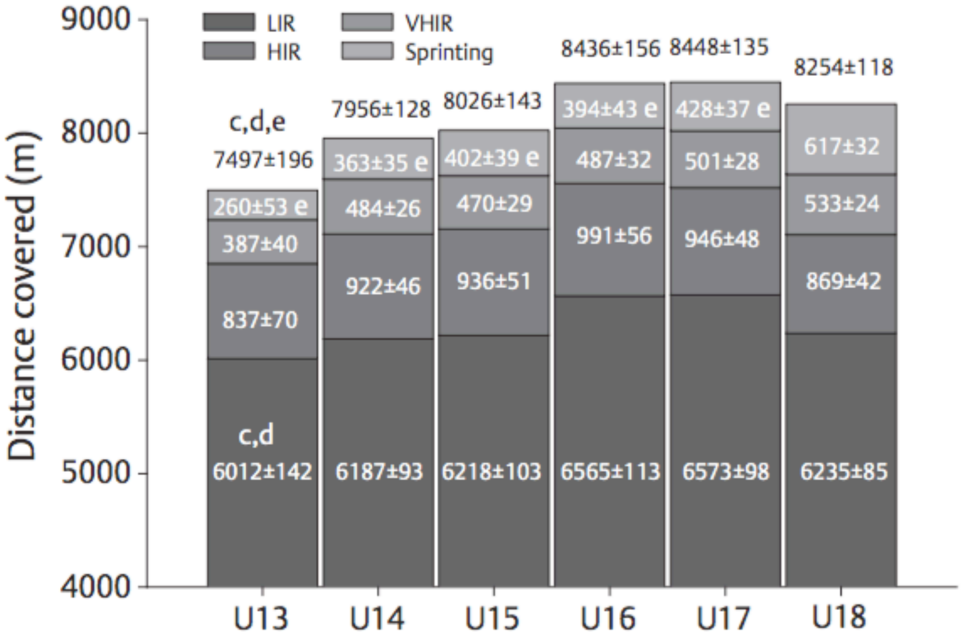

Figure 3.8 Match running performance in U13, U14, U15, U16 and U17 soccer players (Buchheit et al., 2010).

The increased age-distance covered during match play may be due to growth, training and the associated improving physiological capacity: $V'O_{2peak}$ ($L \cdot min^{-1}$) in boys increases linearly until to reach a plateau from the age of 8 to 16 years (Armstrong and Welshman; 1994); performance on an intermittent exercise increase with age in elite youth soccer players aged 14–18 years (Roescher et al., 2010). Even if there is an evident increasing in physical capabilities with age, no great age-related increasing in match performance was observed. It is possible that after an improvement from U13 to U14 at older ages the technical and tactical aspects of match play are also changing. Finally, it is also possible that the reported discrepancy is due to differences in playing style (Saward et al., 2016).

However, these results remain difficult to understand. A first problem of this comparison and interpretation is that the match conditions for youth soccer at the elite-level vary, with pitch size and game period length being age dependent (Harley et al., 2010), may be if all players play the same period in the same space they could be able to perform the same total work. Obviously, this could not be an appropriate stimulus in young soccer players.

Table 3.4 Speed zone thresholds by age-group calculated from 10 m flying time. Speed zone represent: (1, standing; 2, walking; 3, jogging; 4, running; 5, high speed running; 6, sprinting) (Harley et al, 2010).

	10 m flying time (mean ± s)	Speed Zone ($< m \cdot s^{-1}$)					
		1	2	3	4	5	6 ($\geq m \cdot s^{-1}$)
Senior	*1.20*	*0.50*	*2.00*	*4.00*	*5.50*	*7.00*	*7.00*
U16	1.31 ± 0.06 *	0.46	1.83	3.66	5.04	6.41	6.41
U15	1.35 ± 0.09 *	0.44	1.78	3.56	4.89	6.22	6.22
U14	1.51 ± 0.08	0.40	1.59	3.18	4.37	5.56	5.56
U13	1.52 ± 0.07	0.39	1.58	3.16	4.34	5.53	5.53
U12	1.58 ± 0.10	0.38	1.52	3.04	4.18	5.32	5.32

Another problem in the analysis of match data is related to the data about the distance covered by players in a series of defined speed thresholds. It would be not appropriate to use the speed thresholds commonly applied to elite senior players to an elite youth player. In different studies (Capranica et al., 2001; Strøyer et al., 2004), authors have assigned player movement into arbitrary speed categories (e.g. walking, jogging, running) using video analysis and observational coding.

Harley et al., in 2010, used a strong relationship between sprint performance and age in young soccer players normalizing the speed thresholds used in senior soccer players for measured age-related sprint velocities (**table 3.4**). They used a 20 m sprint test with 10 m flying recorded time to calculate the peak velocity for different age group, from U12 to U16. Individual Vpeak (VpeakInd) scores were used to calculate mean Vpeak for each age-group (VpeakGrp), which were compared relative to the mean measured Vpeak for a sample of elite level senior players to calculate group speed threshold ($V_{th}grp$) (eq. 1).

$$V_{th}grp = (VpeakSnr \cdot VpeakGrp^{-1}) \cdot ThS \qquad \text{(eq. 1)}$$

Using this specific-threshold approach Harley et al. (2010) found that U16 age-group displayed higher absolute total distance (U16 > U12, U13, U14), high-intensity distance (U16 > U12, U13, U14, U15), very high-intensity distance (U16 > U12, U13) and sprint distance (U16 > U12, U13) than their younger counterparts. However, when the distance is expressed in relation to match time (m•min^{-1}) that work-rate profiles of elite youth soccer players are similar between the age-levels of U12-U16 using age-specific speed threshold to define movement categories (**figure 3.9**).

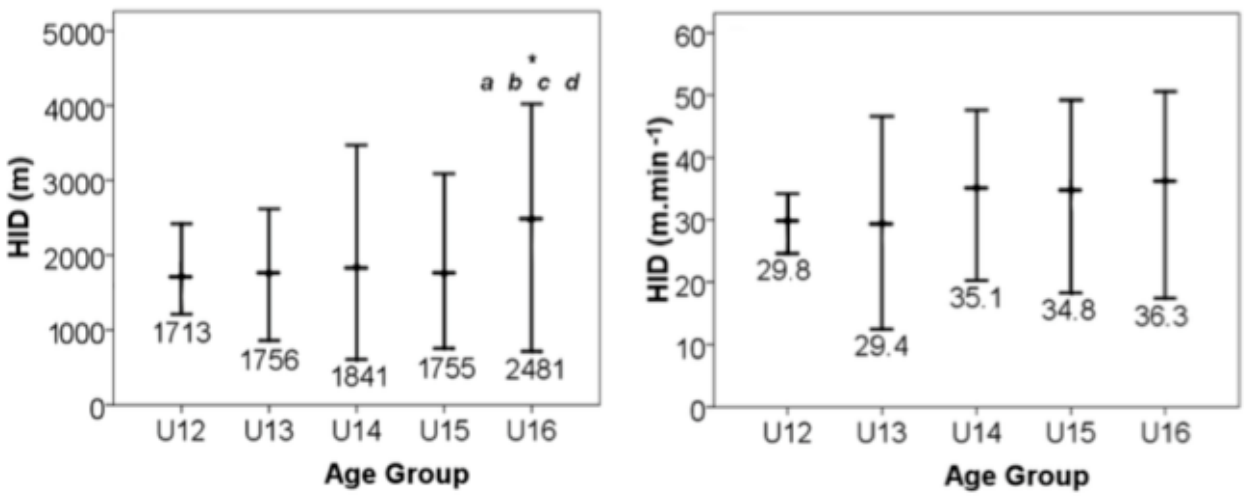

Figure 3.9 Absolute (m) and relative ($m \cdot s^{-1}$) high-intensity distance for U12, U13, U14, U15 and U16 age-group (Harley et al., 2010).

As for very young players (<11 years of age), data describing the activity profile during match play are limited, and thus a less clear picture of the movement demands of these developing players is evident. Capranica et al. (2001) compared the activity profiles of young players during matches (11vs11 and 7vs7) on a regular (100 x 65 m) and small pitch (60 x 40 m), respectively. This study demonstrated that a higher pro- portion of game time was spent in running than in walking in both conditions (55 vs 38%), but no information was provided on the distances covered during games in various speed thresholds. Similarly, Randers et al. (2014) found that the total distance covered by young players was unchanged between matches (5vs5 and 8vs8) played on a 3040 and 53 x 68 m sized pitch, respectively. This trend was further confirmed by Goto et al. (2015) where U9 and U10 age groups covered a total distance of ~4000 m and a high-intensity running distance of ~600 m during a match. However, in players <11 years of age the match running performance has been rarely correlated to physical capacities evaluated by field and/or laboratory fitness assessments (Goto et al., 2015). Since physical performance and training status are important determinants of the physical match performance, it would be of interest to study the relationship between running performance and physical capacities in very young soccer players.

Monitoring training using GPS technology

The growing advancement of GPS Technology allowed the evaluation of player's external load during specific training in soccer. To increase the chances to improve players performance, coaches implement workloads according to what the players are able to achieve, but without exceeding their tolerance limits. The monitoring of load is an important tool for periodization of training and assessment of the physical 'dose' given during training and match play. GPS data provides an improvement in the ability of scientists, coaches and clinicians to monitor individual athlete's workloads especially in the team sport setting, such as soccer game (Wehbe et al., 2014). As reported from Orchard et al. (2012), it would be possible that both inadequate and excessive training loads would result in increased injuries risk, reduced fitness and poor team performance (**figure 4.1**).

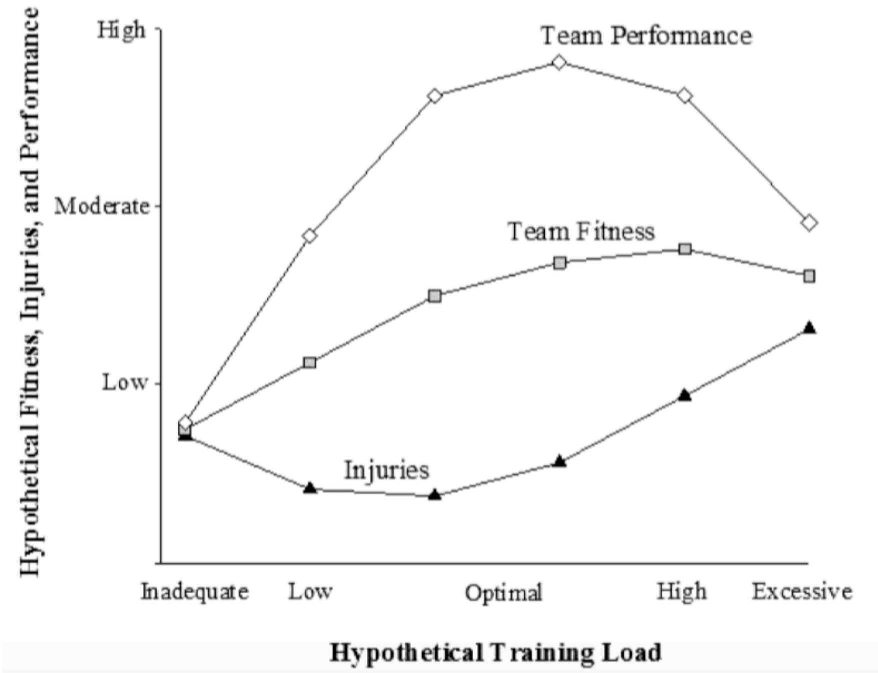

Figure 4.1 Hypothetical relationship between training loads, fitness, injuries and performance (Gabbett, 2016).

Despite the raising interested, researches into the association between these training loads and injury are still lacking. A higher injury risk (e.g., muscle strain, non-contact injuries, etc.) has been found with increased acute GPS-derived workloads in Australian football and rugby league (Piggot et al., 2009; Gabbett et al., 2012). Ehrmann et al. (2016) investigated the relationship between GPS variables measured in training and injury occurrences in professional soccer by identifying two GPS variables that were related to noncontact soft tissue injuries in professional soccer: 1) a significant increase in meters per minute across 1- or 4-week blocks; 2) a significant decrease in new body load across 1- and 4-week blocks. This recent interpretation allows to design a training program in which the correct workload is related to a progressive administration of training stimulus. Thus, it provides an indication of whether the athlete's acute workload (during 1 week) is greater, lower or equal to the workload that the athlete has been prepared during the preceding chronic period (at least the mean of the previous 4 weeks) (Hulin et al., 2016). The principal aim of coaches, in terms of injuries prevention and performance improving, is to program an appropriate balance between training, competition and recovery (Bowen et al., 2016). Hulin et al., in 2016, introduced the acute : chronic (A:C) workload ratio. This new interpretation of GPS data follows a basic methodological principle of training: rapid and excessive, increase in load amplify the risk of injury, whereas chronic exposure to higher loads increases the athletes physical skills making them more resilient to injury and also enhancing performance. More in details, Ehrmann et al. (2016) found in soccer players 'spikes' (an) acute load related to chronic load (i.e., when the A:C workload ratio exceeded 1.5) were associated with an increased risk of injury. In terms of injury risk, A:C workload ratios within the range of 0.8–1.3 could be considered the training "sweet spot", while A:C workload ratios >1.5 represent the "danger zone" (Gabbett, 2016) (**figure 4.2**).

However, more insights are needed to better understand the relationship between injuries and workloads assessed by the use of GPS technology.

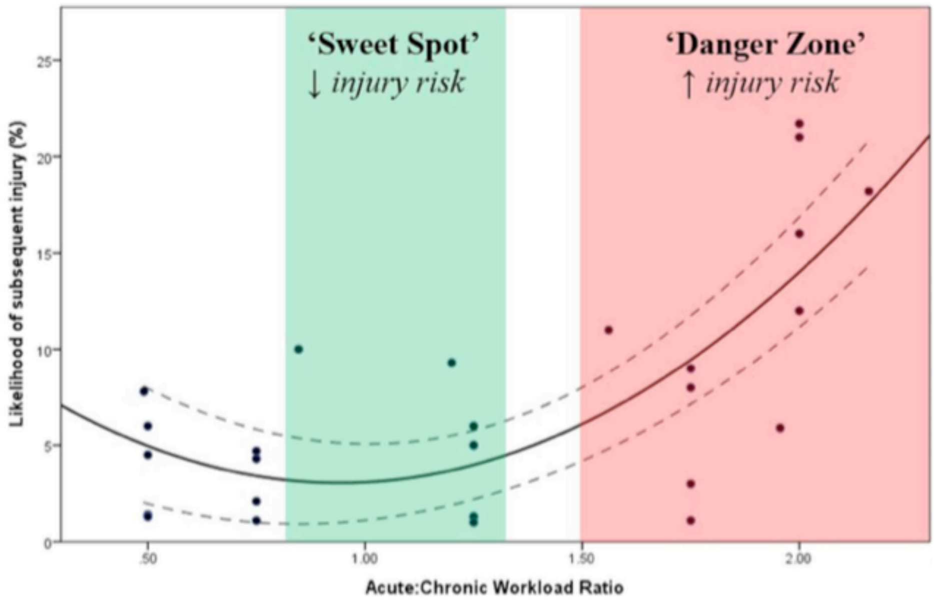

Figure 4.2 Guide to interpreting and applying acute:chronic workload ratio data proposed by Gabbet (2016). The green-shaded area ('sweet spot') represents acute:chronic workload ratios where injury risk is low. The red-shaded area ('danger zone') represents acute:chronic workload ratios where injury risk is high. To minimize injury risk, practitioners should aim to maintain the acute:chronic workload ratio within a range of approximately 0.8–1.3. (Gabbett, 2016).

Furthermore, GPS technology could also help to better understand the intensity or total work load about one training session or the physiological effect of different exercise in relation to GPS data. No data are presented in literature about the relationship between different types of training and different muscle fatigue responses, probably because trying to define the exercise intensity using GPS data could be very difficult. There are too many variables in specific soccer training to consider: speed categories, acceleration and deceleration, change of direction, jump, tackle and with the new metabolic approach: metabolic power categories, average metabolic power, equivalent distance, equivalent distance index and many others. Future researches are needed to better investigate the use of GPS technologies in order to define the intensity of specific training in soccer related to different type of exercise.

Study 1

Accuracy and reliability of GPS for measuring mean and peak speed of shuttle sprints

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Running head: GPS for shuttle sprints analysis

In preparation

ABSTRACT

Purpose. To evaluate the accuracy and inter-unit variability of a global positioning system (GPS) device with sampling rate of 20Hz for measuring mean and peak speed during short distance shuttle runs. Methods. Six amateur soccer players (age: 27±1years, body mass: 72.3±4.1kg and height: 177±6cm) performed 6 shuttle sprints of 4×5m and 6 of 4×10m (n° total=72). Subjects wore two portable GPS devices with a different sampling rate (20Hz and 10Hz). A High-Frequency (HF) camera with a sampling rate of 250fps was used as reference method. Results. Mean speed obtained by GPS devices during shuttle sprint was significantly lower ($P<0.01$) than that obtained from HF Camera. Typical error (TE) and percentage bias between GPS-20Hz and HF camera for mean and peak speed were significantly smaller than those reported between GPS-10Hz and HF camera. Inter-unit variability analysis for GPS-20Hz showed TE of 3.3% and 2.4% and percentage bias of -8.3% and -5.5% for measuring mean speed in 5 and 10m shuttle runs, respectively. TE and percentage bias for measuring peak speed were 5.6% and 4.2% in 5m shuttle runs and -14.2% and -9.8% in 10m, respectively. Conclusion. GPS device with sampling rate of 20Hz tends to be more accurate than that with 10Hz sampling rate for measuring mean and peak speed during short distance shuttle runs.

Keywords: 20hz device, validity, team-sport activities, training analysis

INTRODUCTION

Many team sports (i.e. rugby, soccer, basketball) are characterized by an "intermittent game model" where players cover distances shorter than 10m and repeat short runs with acceleration-deceleration actions, changes of direction and sprints separated by short recovery pauses (Little & Williams, 2005). The most common method to quantify these high-intensity intermittent activities is to determine the distance covered above a specific running speed (Bradley et al, 2009).

In the last years global positioning system (GPS) technology has been extensively utilized to estimate the physical demands of training and competition (Aughey, 2011). In particular, several studies have demonstrated that GPS devices have a sufficient level of accuracy for monitoring the true demands of intermittent exercise and calculate the mean metabolic power during high-intensity activities (Rampinini et al., 2015). However, there are several concerns related to the use of GPS devices to measure very high-speed bouts and it has been shown that the sample rate of the devices, as well as speed, effort duration and nature of the task affect the accuracy (Coutts & Duffield, 2010). Moreover, other studies have shown that reliability of GPS devices gradually decreases in relation to increasing number of changes of directions and accelerations and to reducing running distance (Castellano et al., 2011; Jennings et al., 2010; Portas et al., 2010). The authors investigated the validity and accuracy of GPS technology with a sampling rate of 1Hz, 5Hz or at the most of 10Hz and they showed that the sampling rate is an important parameter to improve the measure exactitude in short high-intensity activities. Nagahara et al. (2016) showed that concurrent validity for obtaining mechanical properties during straight-line sprint acceleration was better using 20Hz GPS device than that obtained from 5Hz GPS device, even if GPS units are not recommended to measure the sprint acceleration mechanical properties. To our knowledge no studies evaluated if a device with a sampling rate >10Hz could produce better information on speed during short shuttle runs than device with a sampling rate <10Hz.

The aim of this study was to evaluate the accuracy and inter-unit variability of a GPS device with a sampling rate of 20Hz for measuring mean and peak speed of shuttle runs. A High-Frequency (HF) video system was utilized as a reference measure. Moreover, mean and peak speed recorded by 20Hz GPS device were compared to the same data obtained by a 10Hz GPS device.

METHODS

Six amateur soccer players (age: 27±1years, body mass: 72.3±4.1kg and height: 177±6cm) performed 72 shuttle sprints covering different distances: 36 bouts of 4×5m and 36 bouts of 4×10m with changes of direction of 180°. During 36 bouts (18 sprints of 5m and 18 sprints of 10m), players wore two portable GPS devices with the same sampling rate of 20Hz (GPEXE, Udine, Italia) for inter-unit variability assessment. Data for between-device comparisons were obtained from the remaining 36 bouts using one 10Hz device (Catapult Minimax S4 Melbourne, Australia - 10Hz) and one of the two GPS devices previously utilized. GPS devices were positioned on the upper back of the players in a custom-made vest. During the entire testing session, data were also recorded by a High-Frequency camera (EXILIM, EX-ZR1000, Casio, Japan) operating at a sampling frequency of 250fps. A recent studies has used this system to analyse cinematics of movement10 and the sampling rate of our camera was at least 15% higher than those utilized in those studies. In 2014, Balsalobre-Fernandez et al. showed that a High-Frequency camera (240fps) and Kinovea as software to analyse video to evaluate flight time of the vertical jump was a method extremely precise, reliable, and valid. In running activity, this system could be used to calculate the start and the end time with the method proposed by Balsalobre-Fernandez et al. (2014). The path for each shuttle distance was delimited by cones placed every 1m on three parallel lines separated by 0.5m, allowing a correction for parallax errors. Video images were analysed by means of an open-source software (Kinovea, http://www.kinovea.org). Two led markers were positioned at the hips exactly placed at the anterior superior iliac spines (assumed to represent the body center of mass) and during the video analysis, they were digitized frame by frame for each shuttle run and for each subject. The mean speed was calculated as ratio between the total distance for each shuttle and time measured by Kinovea analysis. The instantaneous horizontal speed values were calculated and interpolated by means of a 2nd order polynomial regression in order to obtain the maximal speed value.

Descriptive statistics were calculated for all variables and reported as mean and standard deviation (SD). To establish the difference between the reference measure and the GPS devices (10Hz and 20Hz) a one-way ANOVA test was used (Prism 6.0, Graphpad). Typical error (TE) expressed as a percent of the subject's mean score and relative 90% confidence limits (CL) and the percentage bias with 90% CL were calculated using Hopkins' spreadsheet (http://www.sportsci.org/resource/stats/relycalc.html#excel) (Hopkins, 2000). Pearson's correlations and 90% CL were computed between the GPS (20Hz and 10Hz) and HF camera. Significance was set at $P<0.05$.

RESULTS

Table 5.1 shows the mean and peak speed measured by High-Frequency (HF) Camera, 20Hz and 10Hz GPS devices during 4×5m and 4×10m shuttle sprints. During shuttle sprints, mean and peak speed obtained by GPS devices was significantly lower ($P<0.01$) than that obtained by HF Camera.

Table 5.2 reports TE (90% CL), bias as percentage (90% CL) and Pearson's correlation between the mean and peak speed measured using the two GPS devices and the reference system. GPS-10Hz showed a significantly higher TE and percentage bias than GPS-

20Hz both for 4×5m and 4×10m shuttle runs. Pearson's coefficient was significantly higher when mean and peak speed were determined by GPS-20Hz as compared to GPS-10Hz.

The comparison of mean speed measured by two 20Hz GPS devices showed small variations, with TE of 2.7% and 3.7% and percentage bias of -1.6% and 0.8% for 5m and 10m runs, respectively.

As for 20Hz GPS intra device reliability for measuring peak speed we found TE of 2.6% and 4.4% and percentage bias of -0.6% and 0.3% in runs of 5 and 10m, respectively.

DISCUSSION

The purpose of this study was to evaluate the accuracy and reliability of 20Hz GPS devices for measuring mean and peak speed of repeated shuttle runs at different distances. The main finding was that 20Hz GPS device was more accurate than the 10Hz device for measuring both parameters, but with an increasing error in relation to reducing distance on the shuttle run.

Recent studies (Jennings et al, 2010) showed a reduction of the standard error from 25% to 10% when comparing 10 and 40m sprinting. This was reduced even more dramatically to just 1.5% for 5Hz GPS over a 197m simulated high-intensity soccer activity (Portas et al., 2010). Moreover, it is known that the higher the sample rate, the more precise GPS becomes for measuring speed (Castellano et al, 2011; Jennings et al., 2010). Our findings showed that the accuracy of 20Hz GPS device for measuring mean speed of shuttle runs over 5 and 10m was higher than that obtained by a 10Hz GPS device. Indeed, typical error of 20Hz GPS device was lower than that obtained by 10Hz GPS in 5 and 10m shuttle runs, respectively. Thus, our results confirm the importance of the sampling rate of GPS devices for improving accuracy of the measure mean speed during high-intensity activities.

As for peak speed measures during 5 and 10m shuttle runs we showed no differences 20Hz and 10Hz GPS devices in 4×10m shuttle run, whereas at a shorter distance (4×5m) peak speed determined by 10Hz GPS device was significantly lower than that determined by a 20Hz device.

These results confirm the importance of the sampling rate of GPS devices for determining properly peak speed during short-distance sprints. The maximal values of speed reached in our experiments were below the threshold of 5.56 $m \cdot s^{-1}$ usually considered as limit for very high-speed running. Thus, it is plausible that the difference in estimating speed between 10Hz and 20Hz would be greater at higher running speed.

In conclusion, the main finding of this study was that the 20Hz GPS device was generally more accurate than GPS-10Hz for measuring mean and peak speed in shuttle sprints. Thus, a GPS device with a sampling rate of 20Hz should be used for accurately monitoring the energetic demand of intermittent team-sports activities in order to develop more specific training programs and better estimate physical performance during matches. Nevertheless, we acknowledge that these results are related to the specific GPS devices utilized in the present study. Accordingly, it is not possible to exclude a different result when using different software or GPS hardware not examined in this project.

Table 5.1 Mean and peak speed measured in 4×5m and 4×10m shuttle sprint with High-Frequency (HF) camera, GPS-20Hz and GPS-10Hz.

	HF camera	GPS-20Hz	GPS-10Hz	ANOVA p value
		Mean Speed ($m \cdot s^{-1}$)		
4 × 5 m	2.92 ± 0.115	2.67± 0.29*	2.30 ± 0.30*#	> 0.0001
4 × 10 m	3.46 ± 0.14	3.27 ± 0.18*	3.09 ± 0.23*#	> 0.0001
		Peak Speed ($m \cdot s^{-1}$)		
4 × 5 m	4.57 ± 0.34	3.84 ± 0.23*	3.70 ± 0.53*#	> 0.0001
4 × 10 m	5.61 ± 0.38	5.02 ± 0.30*	4.67 ± 0.43*	> 0.0001

*significantly different from HF camera. #significantly different from GPS-20Hz, P<0.05.

Table 5.2 Typical errors (90% CL), percentage bias (90% CL) and Pearson's coefficient between mean and peak speed measured using GPS technologies (10Hz and 20Hz) and mean and peak speed measured using High-Frequency (HF) camera.

	TE as CV (%)		Bias (%)		Pearson's coefficient	
	HF Camera vs GPS-20Hz	HF Camera vs GPS-10Hz	HF Camera vs GPS-20Hz	HF Camera vs GPS-10Hz	HF Camera vs GPS-20Hz	HF Camera vs GPS-10Hz
			Mean Speed ($m \cdot s^{-1}$)			
4x5 m	3.3 (2.7; 4.1)	3.2 (2.5; 4.6)	-8.3 (-10.8; -6.4)	-19.6 (-25.5; -17.8)	0.63 (0.42; 0.77)	0.27 (0.15; 0.61)
4x10 m	2.4 (2.0; 3.1)	3.2 (2.5; 4.5)	-5.5 (-6.5; -4.8)	-11.3 (-14.2; -9.8)	0.82 (0.69; 0.89)	0.54 (0.18; 0.77)
			Peak Speed ($m \cdot s^{-1}$)			
4x5 m	5.6 (4.9; 6.3)	7.4 (6.3; 8.9)	-14.2 (-16.6; -15.4)	-18.4 (-22.5; -18.0)	0.73 (0.64; 0.80)	0.37 (0.14; 0.56)
4x10 m	4.2 (3.7; 4.7)	5.9 (5.0; 7.1)	-9.8 (-10.9; -9.8)	-11.8 (-13.8; -11.2)	0.78 (0.71; 0.84)	0.54 (0.35; 0.68)

Study 2 -

Match running performance and physical capacity profiles of U8 and U10 soccer players

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Running head: Match analysis of very youth soccer

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ABSTRACT

This study aimed to characterize match running performance of very young soccer players and evaluate the relationship between these data and physical capacities and technical skills.

METHODS. Distances covered at different speed thresholds were measured during 31 official matches using GPS technology in U10 (n=12; age 10.1±0.1 yr) and U8 (n=15; age 7.9±0.1 yr) national soccer players. Counter movement jump performance (CMJ), 20 m shuttle running (20m-SR), linear sprint performance (10, 20, 30 m), shuttle (SHDT) and slalom dribble tests (SLDT) were performed to determine the players physical capacities and technical skills.

RESULTS. Physical capacities and technical skills were higher in U10 versus U8 players ($P<0.05$, Effect Size [ES]: 0.99-2.37), with less pronounced differences for 10 m sprint performance ($P>0.05$, ES: 0.74). The U10 players covered more total (TD) and high-intensity (HIRD) distance than their younger counterparts ($P<0.05$, ES: 3.07-1.73). HIRD, expressed as percentage of TD, produced less pronounced differences between groups ($P>0.05$, ES: 0.99). TD and HIRD covered across the three 15 min periods of match-play did not decline ($P>0.05$, ES: 0.02-0.55). Very large magnitude correlations were observed between the U8 and U10 players performances during the 20m-SR versus TD ($r=0.79$; $P<0.01$) and HIRD ($r=0.82$; $P<0.01$) covered during match-play.

CONCLUSIONS. Data demonstrate differences in match running performance and physical capacity between U8 and U10 players and large magnitude relationships between match-play measures and physical test performances. These findings could be useful to sports science staff working within the academies.

KEYWORDS

Match-analysis, GPS, children, football, high-intensity.

INTRODUCTION

The most common method to quantify the physical demands during training or match-play in team sports (e. g. soccer, rugby, cricket, Australian football) is to determine the distance covered or the time spent at different speeds (Bradley et al., 2009; Mohr et al., 2003). To achieve this goal, Global Positioning System (GPS) technology has been used in a multitude of sports (Aughey et al., 2011) and several studies have demonstrated that GPS devices have a sufficient level of accuracy for monitoring movements and speed during high-intensity activities in field-based team sports (Rampinini et al., 2015).

Although this method does not take into account metabolically taxing activities such as accelerations and multi-directional movement (Aughey & Varley; 2013) it does provide an indirect measure of energy expenditure. As such, numerous studies have included this approach to examine the physical demands of match-play across tiers and competitive standards (Mohr et al., 2003; Bradley et al., 2013; Bradley et al., 2016; Di Salvo et al., 2013), positions (Bush et al., 2016), environments (Mohr et al., 2010), surfaces (Andersson et al., 2010) and phases of the season (Rampinini et al., 2007). Particular attention has focused on the relationship between match running performance and physical capacity (Bradley et al., 2013; Bradley et al., 2011; Krustrup et al., 2003; Krustrup et al., 2005) to highlight how variance is shared between measures.

Match analysis research has extensively studied senior male players of sub-elite to elite competitive standard (Mohr et al., 2003) whereas for youth players most information is available for players between 12 and 17 yr of age (Saward et al., 2016; Buchheit et al., 2010; Castagna et al., 2009; Castagna et al., 2010; Harley et al., 2010; Rebelo et al., 2014). In this age range, it appears that the total and high intensity running distance covered during matches are affected by training status (Aquino et al., 2016), and are greater in older players than in their younger counterparts (Saward et al., 2016). Barbero-Alvarez et al. (2016) compared the activities demand of 7-a-side soccer matches across two different age-group (U14 vs U12) showing that older players covered more high intensity and sprint distance than U12. A possible explanation of this age-related increment of match-running performance may be due to the improving physiological capacity associated with growth and training (Saward et al., 2016), such as $V'O_2$ peak that increases linearly with age, from 8 to 16 years (Amstrong & Welshman, 1994). Indeed, in a recent study (Castagna et al., 2010; Lang et al., 2016) strong relationships have been reported in male youth soccer players (age >15 years) between the total and high intensity running distance covered during the match and aerobic fitness, as determined by shuttle running test.

As for very young players (<11 yr of age), data describing the activity profile during match play are limited and thus a less clear picture of the movement demands of these developing players is evident. In 2016, Saward et al. examined changes in match-running performance in relation to age in young soccer players aged 8-18 years and they showed that total distance increase up to reach a plateau at 17.7 years. Capranica et al. (2001) compared the activity profiles of young players during matches (11 vs 11 and 7 vs 7) on a regular (100 × 65 m) and small pitch (60 × 40 m), respectively. This study demonstrated that a higher proportion of game time was spent in running than in walking in both conditions (55 vs 38%), but no information was provided on the distances covered during games in various speed thresholds. Similarly, Randers et al (2014) found that the total distance covered by young players was unchanged between matches (5 vs 5 and 8 vs 8) played on a 30 × 40 m and 53 × 68 m sized pitch, respectively. This trend was further confirmed by Goto et al. (2015) whereby U9 and U10 age groups covered a total distance of ~4000 m and a high-intensity running distance of ~600 m during a match. However, in players <11 yr of age the match running performance has been rarely correlated to physical capacities evaluated by field and/or laboratory fitness assessments (Goto et al., 2015). Since physical performance and training status are important determinants of the physical match performance, it would be of interest to study the relationship between running performance and physical capacities in very young soccer players.

Thus, this study aimed to quantify the match running performances of very young soccer players during official games of the Federazione Italiana Giuoco Calcio (FIGC) in relation to their physical capacity.

METHODS

Youth Players

Twelve U10 and fifteen U8 Italian national team youth soccer players were recruited for this study. Mean age, stature, and body mass in U10 and U8 players were 10.1±0.1 and 7.9±0.1 yr, 1.41±0.01 and 1.33±0.01 m ($P<0.05$) and 34.1±0.9 and 29.1±1.2 kg ($P<0.05$), respectively. The mean peak height velocity (PHV) indirectly estimated by the leg length (Sherar et al., 2005) was -3.1±0.1 and -4.6±0.1 yr in U10 and U8 players ($P<0.05$), respectively. Players trained approximately 4 hr per week and partook in 1 or 2 match per week. Players possessed at least 3 years of experience in soccer training and competitions.

Experimental Approach to the Problem

Each player completed the battery of field tests to determine individual physical capacity and technical skills the week before the first match' observations. Match data were collected across an eight-week period and data were only analysed if the player completed the entire game. All matches were played in accordance with the rules outlined by the FIGC.

Physical Capacity and Technical Skill Tests

Players underwent: counter movement jump performance (CMJ), 20 m shuttle running (20m-SR), linear sprint performance (10, 20, 30 m), shuttle (SHDT) and slalom dribble tests (SLDT) (Lemmink et al., 2004; Mahar et al., 2011; Markovic et al., 2004). Each test was conducted on a different day for each age group with at least 24 h of recovery. The players were instructed and verbally encouraged to give a maximal effort during every testing session. All test sessions were performed in the afternoon at the same hour of the day (16:00) on artificial-grass soccer pitch at a temperature of 22.4 ± 0.9°C and a relative humidity od 39 ± 11.5%.

Players performed three CMJ keeping their hands on the hips during the jump to prevent any influence of arm movements and the best jump was classed as the criterion measure. Jump height was estimated from flight time using photocell mat (Optojump, Microgate, Italy) connected to a portable computer. A photocell system (Microgate, Italy) was used to record times at 10, 20 and 30 m. Each test was performed three times with 2-3 min recovery and the best performance was recorded. During the 20 m sprint test an additional photocell was positioned at 10 m in order to obtain a flying-10m (FL10m) sprint time (Harley et al., 2010). In 20m-SR players were instructed to run back and forth between two cones placed 20 m apart from each other at an increasing speed controlled by audio bleeps from a CD player. According to Mahar et al. (2011) this test was interrupted when a player failed twice to reach the appropriate marker or the player felt unable to complete another shuttle at the required speed. The total distance covered during the test was recorded as the test result. Technical skills were examined in the SHDT and SLDT tests which were both performed over a 30 m distance (Lemmink et al., 2004). SHDT consisted of maximal sprints while dribbling a ball with three 180° turns. SLDT consisted of maximal sprints while dribbling a ball between twelve cones placed in a zigzag pattern. Timing data were measured using photocells system and the fastest of the three trials was recorded (Lemmink et al., 2004).

Match Running Performance

Distances covered at different speed thresholds were measured during 31 official matches using GPS technology in U10 (58 observations) and U8 (61 observations). All matches were played on artificial-grass soccer pitch. Air temperature was 24.1 ± 0.7°C with a relative humidity of 42.2 ± 11.5%, respectively. To avoid dehydration, ad libitum drinking was permitted to the players. Only players completing the entire match were considered for further analyses with 62 observations excluded for this reason. The duration of each period was the same in U10 and U8 games (3 × 15 min) but the pitch dimensions (60 × 40 m and 45 × 25 m, respectively) and the number of players (7 vs 7 and 5 vs 5) were different for U10 and U8. A rolling substitute policy, whereby each individual player can interchange with any substitutes an unlimited number of times during the match was adopted according to the rules of the FIGC.

During matches, players wore a portable GPS device (K-Gps 10 Hz, K-Sport, Italy) positioned on the upper back in a custom-made vest. The mean number of satellites connected during the match was 9.5±1.8. Several studies have investigated the validity and reliability of GPS devices for measuring movements and speeds (Rampinini et al., 2015) and, as reported in a recent study (Varley et al., 2012), a sample rate of 10 Hz is sufficiently accurate to quantify the very high intensity, acceleration and deceleration running phases in team sports. The validity of the GPS unit utilized in the present study was previously assessed in a pilot study. Seven adult male soccer players performed three trials in a specific circuit (372 m) while wearing a GPS unit. No significant difference ($p>0.05$) was found between the actual vs GPS detected distances. The magnitude of the difference was 2.3±0.9% thus similar to that reported as acceptable for the most used match analysis system currently available (Carling et al., 2008).

The data recorded during the matches were exported using specific software (K-Fitness, K-Sport, Italy) and subsequently combined in a customised spreadsheet for analysis.

According to Saibene & Minetti (2003), thresholds between walking and jogging were estimated using the equation:

$$v= \sqrt{(Fr \cdot g \cdot L)}.$$

Where v is the speed of progression (m•s-1), Fr is Froude number, g is acceleration due to gravity (9.81 m•s^{-2} on Earth) and L is leg length, in m. An Fr of 0.5 was utilized since it has been shown corresponding to the spontaneous transition speed between walking and running. The other speed thresholds were established according to Harley et al. (2010) using the mean peak speed of FL10m in each group (vpeakGrp). This velocity was compared relative to the corresponding value reported in elite senior players (vpeakSnr). The [vpeakGrp • vpeakSnr-1] ratio was then applied to the commonly used thresholds for senior players by Bradley et al ([1])to produce group specific speed zones. The speed thresholds for various activities for U10 and U8 were: 1) walking; 2) jogging; 3) running; 4) high-speed running and 5) sprinting (Table 6.1). Total distance (TD) was the sum of the distances covered in each of above speed thresholds. High-intensity running distance (HIRD) was the summation of running, high-speed running, and sprinting distances.

Statistical Analysis

Data are expressed as means ± standard deviations (SD). Based on mean and SDs for the total and high intensity distances measured in preliminary trials, an n value of 10 for each group was calculated to be sufficient to detect significant differences between groups, if present, with an alpha level of 0.05 and a beta level of 0.20 (GPower 3.1) (Faul et al., 2009). Before using parametric tests, the distribution of each variable was examined with the Kolmogorov-Smirnov normality test. Homogeneity of variance was verified with a Levene's test. Differences between groups were determined using a unpaired t-test while a one-way analysis of variance (ANOVA) with repeated measures was used to determine differences between distances covered in the first, second, and third match periods. Tukey's post-hoc test was utilized to determine localized effects. Statistical significance was set at $P<0.05$. All analyses were performed using statistical software package (Prism 6.0; GraphPad, San Diego, CA, USA). Effect sizes (ES) were calculated to determine the meaningfulness of the difference with the magnitudes classified as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2) and large (>1.2) (Batterhan et al., 2006). Relationships between the distances covered (TD and HIRD) and physical and technical variables were evaluated using Pearson's product moment test. For this analysis, only the players (n=12 for U8 and n=10 for U10) that completed at least 3 matches were considered. The magnitudes of the correlations were considered as trivial (<0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9), nearly perfect (>0.9) and perfect (1.0) in accordance with Hopkins et al. (2010).

RESULTS

Physical Capacity and Technical Skill Tests

CMJ performance was greater in U10 than U8 players (0.23±0.03 vs 0.21±0.03 m, P<0.05, ES: 0.99). Sprinting performances across 20 m (4.15±0.17 vs 4.38±0.027 s, P<0.05, ES: 1.27) and 30 m (5.72±0.22 vs 6.31±0.31 s, p<0.05, ES: 2.37) were faster in addition to FL10m (1.66±0.07 vs 1.75±0.11 s, p<0.05, ES: 1.27). Less pronounced differences were evident between U8 and U10 players for sprints across 10 m (p>0.05, ES: 0.74). U10 players had a 40% higher 20m-SR test performance than U8 players (1215±77 vs 872±78 m, P<0.01, ES: 1.60) Similarly, SHDT (10.66±0.57 vs 11.80±0.83 s, P<0.01, ES: 1.77) and SLDT performances (22.34±1.28 vs 29.41±2.72 s, p<0.01, ES: 4.50) were better in U10 than U8 players.

Match Running Performance

U10 players covered 34% more total distance than their U8 counterparts (3541±511 m vs 2229±331 m; P<0.01, ES: 3.07, Figure 6.1).

The differences between U10 and U8 were evident in walking (16%), jogging (60%), running (50%), high-speed running (34%) and sprinting (70%) (P<0.01, ES: 0.97-3.13, Figure 6.2a).

HIRD was also found to be greater in U10 than U8 players (1503±391 vs 836±279 m, P<0.01, ES: 1.73). When data were expressed in percentages of TD, differences between U10 and U8 players were observed for walking (36±7 vs 49±7%), jogging (22±4 vs 14±2%), running (24±4 vs 20±4%) and sprinting (2±1 vs 1±1%, p<0.01, ES: 1.12-2.33, Figure 6.2b). Less pronounced differences were evident for HIRD between U10 and U8 (42±6 vs 38±8%, P>0.05, ES: 0.99).

During each of the three periods, TD (1244±202, 1154±196, 1142±189 m and 759±135, 733±148, 735±128 m in U10 and U8, respectively) and HIRD (552±192, 485±136, 466±126 m and 291±130, 263±105, 283±98 m in U10 and U8, respectively) were unchanged (P>0.05, ES: 0.02-0.55, Figure 6.3).

Overall, very large magnitude correlations were observed between the U8 and U10 players 20m-SR performances versus TD (r=0.79; P<0.01) and HIRD (r=0.82; P<0.01) (Figure 6.4a and 6.4b).

No relationships were found between match running performance and any other physical or technical test results.

DISCUSSION

This is the first study that quantified the match running performance and physical capacities of very young Italian soccer players. These findings will contribute greatly to our understanding of the demands placed on very young players and this work could be useful to sports science staff working within club academies. The data demonstrate that during a 45 min match, U8 and U10 players cover a total distance of ~2200 and 3500 m, respectively. Thus, it seems that very young Italian players cover lower total distance during matches than their English counterparts (Goto et al., 2015; Randers et al., 2014). However, comparing the present findings with those from previous studies is problematic given the differences in populations, matches characteristics and GPS technology (Goto et al., 2015; Randers et al., 2014). Indeed, different game formats and pitch sizes were present and it is known that playing with fewer players on smaller pitches results in some changes to the physical load (Randers et al., 2014). Moreover, matches with a greater area per player induce higher heart rates, blood lactate concentrations, and perceived effort (Castellano et al., 2015). In any case, when expressing the present data in relative terms ($m \cdot min^{-1}$), U10 players covered ~78 $m \cdot min^{-1}$ which is substantial different from the U8 players (50 $m \cdot min^{-1}$) but similar to the ~80-90 $m \cdot min^{-1}$ reported in the literature for young players (Saward et al., 2016; Goto et al., 2015; Randers et al., 2014). As expected, these values fall well short of the distances covered in senior matches which vary from 100-130 m•min-1 dependent on competitive standard, tier, position and phase of the season (Moher et al., 2003; Bradley et al., 2013; Bradley et al., 2016; Di Salvo et al., 2013; Bush et al., 2016; Andersson et al., 2010).

The total distance covered is the most commonly reported physical metric in match analysis but not necessarily the most informative or useful, especially given that a large proportion of this distance is covered at low intensity (Bradley & Noakes, 2013). The distance covered at high-intensity seems a much more appropriate physical metric given its ability to distinguish between various soccer populations (Mohr et al., 2003) and its relationship with physical capacity (Aughey et al., 2011). Faude et al. (2012) reported that in elite adult soccer players in 83% of all goals at least one high intensity action of the scoring or assisting player was observed. In the present study, U8 and U10 players covered ~800 and 1500 m, respectively. These values are higher than those reported by other studies. For instance, Goto et al. (2015) found that U9 and U10 players covered just 600 m at high-intensity. One possible reason for this discrepancy may be due to the different data analysis approach. Goto et al. (2015) considered the completion of at least a half of the duration of a match as inclusion criterion whereas we included only players that completed the whole match. Another possible explanation may involve different physical capacities of the players investigated. Furthermore, it is likely that pitch dimensions and tactical-technical aspects may have affected the distances covered in games. Indeed, Casamichana & Castellano (2010) observed greater high-intensity running distances during matches played on large compared to small pitches. Finally, different speed thresholds used to define high-intensity may have altered the results. The present study adhered to the individual approach recommended by Harley et al. (2010). This method created age-specific speed thresholds based on the peak velocity of a flying 10 m sprint. Although this approach was adopted by some studies (Goto et al., 2015), arbitrary thresholds were used by others (Randers et al., 2014). Interestingly, when the present data are expressed as a percentage of the total distance covered, no differences are observed between U8 and U10 players and the values at the upper end of the range are similar to those reported by Harley et al. (2010) for U12 – U16 players. So, a direct comparison among our and other studies can not be performed and this issue will continue to persist until speed thresholds will be standardized for various soccer populations (youth, senior, female and disabled players) (Bradley & Vescovi, 2015).

In elite senior players it has been demonstrated that match running performance are position-dependent (Rampinini et al., 2015; Di Salvo et al., 2007). Buchheit et al. (2010) also observed positional variation in U13 – U18 player regarding the distance covered during matches especially at high-intensity. The same results were also reported by Saward et al. (2016) in elite youth soccer players aged 8-18 years. Our study is not able to quantify positional trend as players were frequently interchanged by the coaches during matches in order to improve technical and tactical abilities.

Match performance data can be split into distinct time periods and simple comparisons of the running performance between the first and second halves of the matches can potentially indicate the occurrence of fatigue. Although, the context (scoreline, location, standard of opposition) and pacing cannot be discounted (Bradley & Nassis, 2015). The present study found no decrement in total and high-intensity running distances during U8 and U10 matches. In a recent survey of the literature it has been reported that elite senior players exhibit a reduction of both total and high intensity distance covered between halves (Mohr et al., 2003), although some studies illustrate comparable performances across halves (Bradley et al., 2013; Rampinini et al., 2007). As for youth soccer, Rebelo et al. (2014) reported that the total distances decrease between the first and the remaining five periods during an 80 min competitive match. Thus, the present findings potentially highlight a fatigue pattern during matches in relation to age. Interestingly, similar results were reported by Castagna et al. (2003) who observed no between half differences in match running performance for young soccer players. The enhanced capacity of children compared with adults of a similar training status, to maintain performance during a task characterized by repeated high-intensity actions seems to be supported by some evidence (Ratel et al., 2006). It has been shown that during a 30 s all-out cycle sprint the percentage decline in power output is lower in children than in adults (Beneke et al., 2005). The greater fatigue resistance displayed by children compared to adults might be related to muscular characteristics of the muscles. Indeed, compared to adults, children: 1) have less muscle mass, and thus generate lower absolute power; 2) have higher muscle oxidative activity and lower glycolytic activity (Ratel et al., 2006); 3) have a faster phosphocreatine resynthesis and might exhibit a higher clearance of lactate and H+ ions within muscles (Beneke et al., 2005). However, the different match activity profile between senior and youth soccer players should be interpreted with caution given the multitude of factors potentially impacting results. To add further to the existing data, it would be of interest to investigate the effects of match location (at home or away), quality of the opponents (weak or strong) and match status on running performance in young soccer players.

Interestingly, this study demonstrated a very large correlation coefficient between 20m-SR test performance, the best and most popular field-based measurement of cardiorespiratory endurance in very young children (Lang et al., 2016), and match running performance. The correlations observed in the present study are larger than those observed in elite senior soccer players/referees (Bradley et al., 2011; Krustrup et al., 2003; Castagna et al., 2009) and in adolescent (Buchheit et al., 2010; Castagna et al., 2009;Rebelo et al., 2014). A potential explanation for these findings could be related to different tactical and technical knowledge of the game and it's important to note that these relationships are high complex. Elite senior players do not tax their full physiological capacity in games due to tactical and technical constraints (Bradley et al., 2013; Bradley et al., 2016; Bush et al., 2016; Barnes et al., 2014) and contextual factors like scoreline (e.g. match performance drops when there is a high score difference). Thus given that young players have a lower tactical knowledge they may tax their capacities more and also evenly across the game. The reader must also be aware of the limitation of using continuous based tests such as the 20m-SR over more intermittent tests such as the Yo-Yo intermittent tests. However, the present findings are similar to Goto et al. (2015) whereby a positive relationship between the Yo-Yo intermittent recovery test performance and the total distance covered in a match was found in both U9 and U10 players.

In conclusion, the data demonstrate differences in match running performance and physical capacity between U8 and U10 players and large magnitude relationships between match play measures and physical test performances. Although physical capacity seems to be an important characteristic for developing young players it should never be placed over and above their technical and tactical development. Future studies in very young soccer players should address the effects of confounding factors such as match location, quality of opponents and scoreline on match running performance.

PRACTICAL APPLICATIONS

These findings will contribute greatly to our understanding of the physical demands placed on very young players during a soccer match-play. The data can be used to profile young players' match-running performance whereby selected information such as the peak 5 min period could be replicated to create age-specific high-intensity drills. This approach has been successful for elite senior players as match-specific drills produce comparable physiological responses to small-sided games but provide a more uniform physiological response (Kelly et al., 2013). Furthermore, the findings provide evidence that performance on the 20m-SR test correlates well with physical match performance, suggesting the possibility to use this simple field test as alternative or in combination to intermittent running tests for very young soccer player. The present data also highlighted that very young players have the ability to maintain their match running performance across the match.

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COMPLIANCE WITH ETHICAL STANDARDS

CONFLICT OF INTEREST

All the authors declare that there is no conflict of interests.

ETHICAL APPROVAL

The study was approved by the appropriate institutional ethics committee with all procedures adhering to the Declaration of Helsinki (2000) of the World Medical Association.

INFORMED CONSENT

The players and their parents were fully informed of any risks associated with the experiments before giving their written consent to participate to the study.

FIGURE 6.1 Total distance (TD) (mean±SD) covered during the match by U10 (black column) and U8 players (white column). *Significantly different (P<0.05).

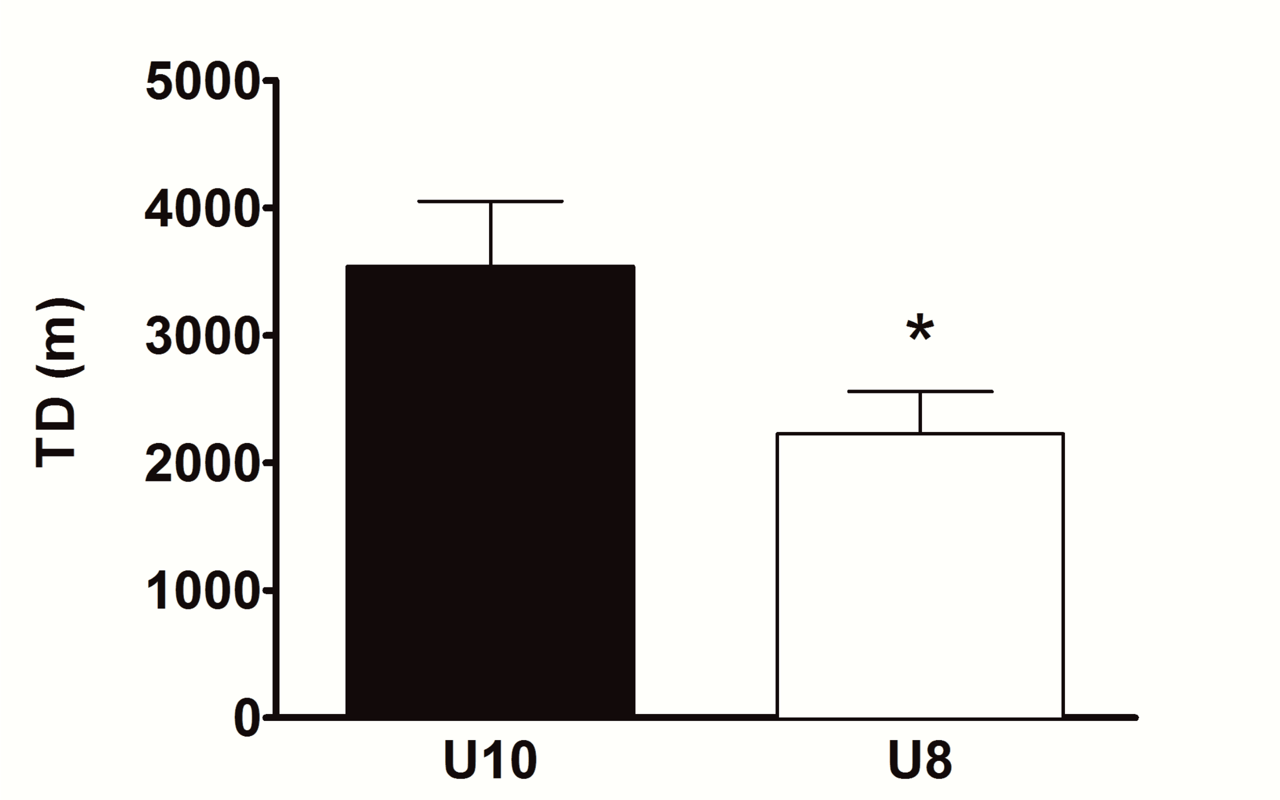

FIGURE 6.2 Distances expressed in meters (left panel) and as percentages of total distance (right panel) covered in walking (S1), jogging (S2), running (S3), high-speed running (S4) and sprinting (S5) during U10 (black columns) and U8 (white columns) matches. *Significant difference (P<0.05) between groups.

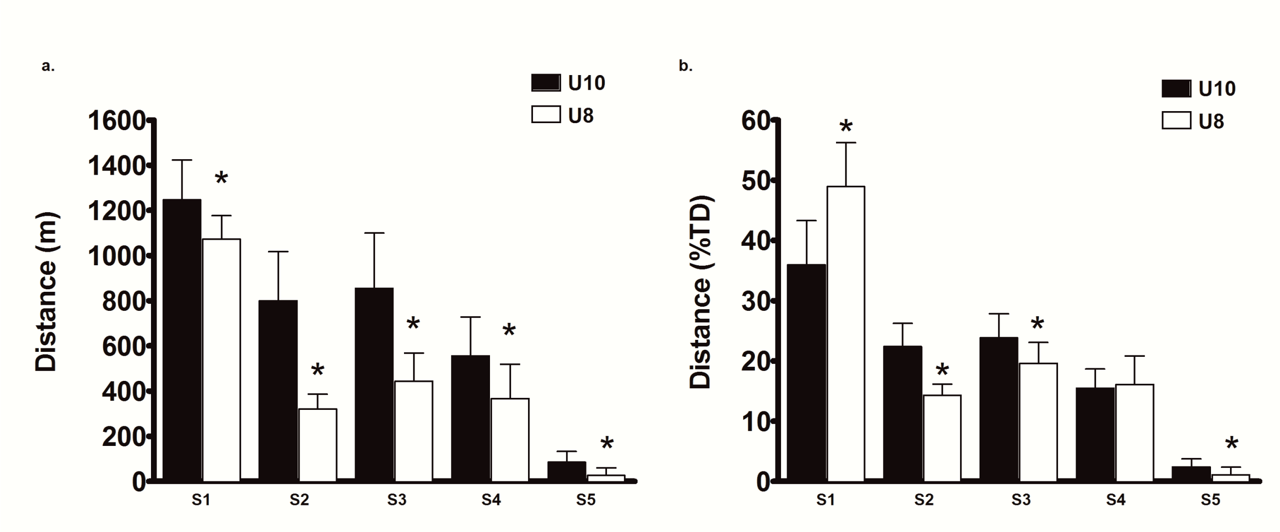

FIGURE 6.3 Total (TD) (left panel) and high-intensity running distance (HIRD) (right panel) covered by U10 (black circles) and U8 players (with circles) during each period of the match. *Significantly different (P<0.05) from U10.

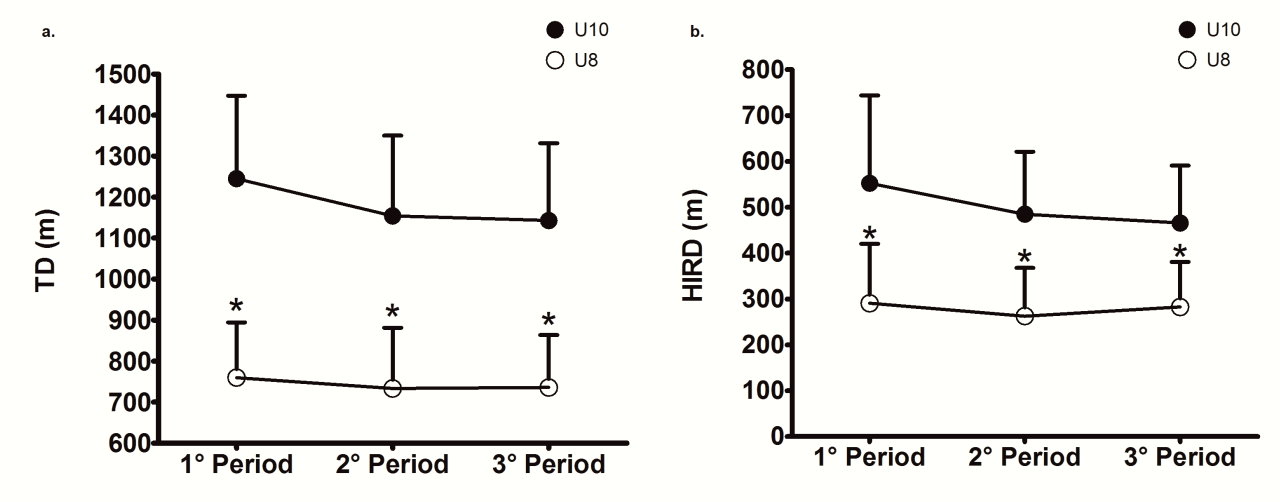

FIGURE 6.4 Relationship between 20-m shuttle run test performance and total (TD) (left panel) and and high-intensity running distance (HIRD) (right panel) covered during matches in U10 (black circles) and U8 players (white circles).

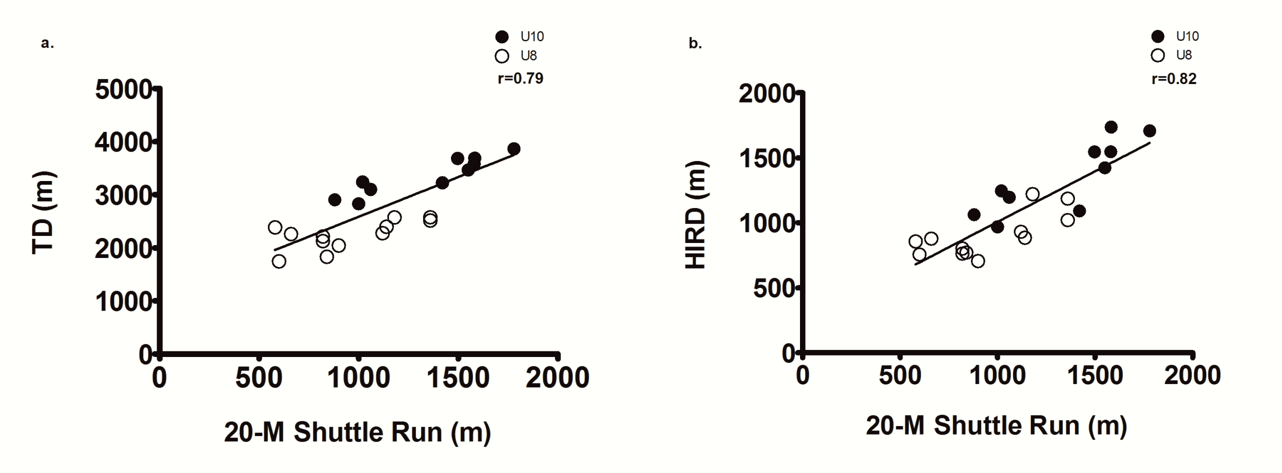

TABLE 6.1 Speed zone thresholds (km·h^{-1}) by age-group.

Group	Walking	Jogging	Running	HS Running	Sprinting
U10 (km·h^{-1})	<6.7	6.8-9.6	9.7-13.2	13.3-18.2	>18.2
U8 (km·h^{-1})	<6.3	6.4-8.4	8.5-11.5	11.6-17.3	>17.3

HS=High Speed

Study 3

High-intensity distance in elite female soccer players: it is time for a gender-specific speed threshold?

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Running head: High-intensity in female soccer match

In preparation

ABSTRACT

Female soccer players spent the majority of match play in low-intensity activities while high-intensity running is approximately 30% lower than their male counterparts. To date, studies on female soccer players have utilized the same absolute speed threshold of male players despite females having a lower physical capacity than males. The aim of this study was to examine high-intensity distance covered during matches by elite female soccer players using different speed thresholds.

METHODS. Nineteen elite female players participated in this study. Maximal oxygen consumption (VO_2max) and respiratory compensation threshold (VT_2) were determined by incremental treadmill test to exhaustion. Players activities across 16 matches (120 observations) were tracked by global positioning system (GPS) technology. Total (TD) and high-intensity running (HID) distance covered were evaluated. The latter was assessed using both the typical male speed threshold of 15 km•h^{-1} (MALE) and a gender-specific speed threshold (FEM) corresponding to VT_2.

RESULTS. Players VO_2max was 49.1±3.7 mL•kg^{-1}•min^{-1} and occurred at a speed value of 14.7±0.8 km•h^{-1}. VT2 corresponded to a running speed of 13.5±0.9 km•h^{-1}. TD covered was 7726±891 m with HID higher ($p<0.0001$) based on FEM (1125±533 m) than on MALE (785±353 m). When expressed as percentage of TD, HID amounted to 14.4±5.8% in FEM and 9.9±3.8% in MALE.

CONCLUSIONS. These data demonstrate that the quantification of HID during female soccer match play can be substantially influenced by applying relative or absolute speed thresholds. Further studies are needed to understand the best method characterizing the multiple transitions between intensity-domains in female soccer.

KEYWORDS

Match-analysis, GPS, female, football, high-intensity, speed threshold.

INTRODUCTION

Global Positioning System (GPS) technology is commonly used to describe the physical demand during soccer match and/or training sessions and to assess the distances covered within different speed zones (Bradley et al., 2009; Di Salvo et al., 2009). Particular attention is given to high-speed-running or high-intensity distance as important indicators of match physical performance (Mohr et al., 2003). These variables are in relation with to the different competitive level of female and male players, are sensitive to the physiological changes associated with the completion of a training program and to variations in stages of the competitive season and tactical role of players (Di Salvo et al., 2009).

Research has extensively studied high-intensity activities in male soccer matches. In several studies the speed thresholds used to define where high-intensity begins were not selected based on the individual physiological responses to effort of the subjects but “a priori” the same for all players. According to this “one size fits all” approach a variety of speed thresholds has been utilized, 13 km•h^{-1} (Mallo, Navarro et al., 2007), 14.4 km•h^{-1} (Rampinini et al., 2007a; Rampinini et al., 2007b), 15 km•h^{-1} (Andersson et al., 2008; Bangsbo et al., 1991), 18.1 km•h^{-1} (Castagna & D’Ottavio, 2001), 19.1 km•h^{-1} (Di Salvo et al., 2007), and 19.8 km•h^{-1} (Weston et al., 2007). Interestingly, Abt et al., (2009), adopting a physiological approach, employed in elite male soccer players the speed threshold (on average 15.3 km•h^{-1}) corresponding at the second ventilatory threshold (VT_2) obtained during an incremental treadmill test.

In the past few decades, the number of female soccer players is worldwide growing; limited studies, however, have assessed the physical demands of female soccer match play. As far high-intensity activity, initial studies (Andersson et al., 2010; Mohr et al., 2008; Krustrup et al., 2005) have simply used in females the same speed threshold employed when describing time-motion characteristics of elite male players. It is not surprising if in this way these studies have reported that high-intensity distance in elite female matches is about 30% lower than their male counterparts. Different authors showed that aerobic performance in female soccer players is significantly lower than in male showing a difference of about 15% in speed at maximal oxygen consumption (VO_2max) reached during treadmill test (Ingebrigtsen et al., 2011; Sirotic et al., 2007) and a difference of about 30% in soccer-specific field test such as Yo-Yo Intermittent Endurance Level 2 (Bradley, Bendiksen, Della et al., 2014). Accordingly, the same external load, represented as distance covered above an absolute speed threshold, produce a different physiological impact in male and female players. To better understand the importance of high-intensity activities and the difference between female and male soccer players it seems to be very important to use appropriate speed threshold with the same (sex-specific) physiological meaning.

The purpose of this study was to determine the running speed corresponding at the second ventilator threshold in elite female soccer players and to compare the high-intensity distance covered during matches using gender-specific and male default speed threshold.

METHODS

Subjects

Nineteen elite female soccer players competing in the 2014-2015 Italian Serie A league were recruited for this study. Mean ± SD age, stature, body mass and BMI were 22.7±3.8 yr, 1.648±6.61 m, 54.7±6.5 kg and 20.1±1.9 $kg \cdot m^{-2}$ respectively. Players trained approximately 8 hr per week and partook in 1 or 2 match per week. Players possessed at least 5 years of experience in elite soccer training and competitions.

Experimental design

After 5 weeks of pre-season training the subjects completed an incremental test until exhaustion on treadmill to determine maximal oxygen consumption (VO_{2max}) and respiratory compensation threshold (VT_2). Match data were collected across 6 following months and data were only analyzed if the player completed the entire game. All matches were played in accordance with the rules outlined by the FIGC.

Incremental test

Each subject completed an incremental test up to voluntary exhaustion to assess VO_{2max} and VT_2. Subjects were instructed to arrive at the laboratory in a rested and fully hydrated state and to avoid strenuous exercise in the 24 h preceding each testing session. All laboratory exercise tests were carried out in a well-ventilated laboratory at 19–21°C on a motorized treadmill (Jaeger, Germany) set at a 1% gradient. Following a 3-minute warm-up at 9 $km \cdot h^{-1}$ then the treadmill speed was increased by 1 $km \cdot h^{-1}$ every minute until volitional exhaustion. The $V'O_{2max}$ was considered to be the highest oxygen volume (30-second average) attained prior to the subject's volitional exhaustion. The criteria for attaining VO_{2max} included any 2 of the following: (a) volitional exhaustion; (b) a respiratory exchange ratio equal to or greater than 1.15; and (c) a plateau in oxygen consumption (increase 2 $ml \cdot kg^{-1} \cdot min^{-1}$) with increased exercise intensity.

During incremental test pulmonary ventilation (VE, in BTPS), O_2 consumption ($V'O_2$) and CO_2 output, both in STPD, were determined breath-by-breath by a metabolic cart (Vmax29c;), (VCO2SensorMedics, Bilthoven, The Netherlands). Expiratory flow was determined by a mass flow sensor (hot wire anemometer). $V'O_2$ and $V'CO_2$ were determined by continuously monitoring PO_2 and PCO_2 at the mouth throughout the respiratory cycle and from established mass balance equations. Gas exchange ratio (RQ) was calculated as $V'CO_2 \cdot V'O_2^{-1}$. At rest and at various times (1, 3, and 5 min) during recovery, 20 μL of capillary blood was obtained from a preheated earlobe for the determination of blood lactate concentration ([La]b) by an enzymatic method (Biosen 5030; EKF, Cosmed, Italy).

The VT2 was calculated according to the method of Foster et al. (2005) and Lucia et al. (2000) and defined as the point where occurred an abrupt increase in the ventilatory equivalent for O_2 (VE $\cdot$V'O_2^{-1}) and CO_2 (VE $\cdot$VC'O_2^{-1}) together with a decrease in the end-tidal partial pressure of CO_2 ($PETCO_2$). After determining the VO_{2max} and VT_2 for each player, the associated treadmill speeds were determined.

Match analysis

Total distance (TD) and high-intensity distance (HID) covered were calculated. The latter was calculated using both the typical male speed threshold of 15 km$\cdot$h^{-1} (MALE) (Krustrup et al., 2005; Mohr et al., 2008; Andersson et al., 2010) and the mean speed threshold (FEM) corresponding to VT_2. During 16 official matches (duration: 2 × 45 min; pitch size: 100 × 50 m) all players wore a portable GPS device with a sampling rate of 10 Hz (K-Gps 10 Hz, K-Sport, Italy) positioned on the upper back in a custom-made vest. The mean number of satellites connected during the match was 9.5±1.8. Only players completing the entire match were considered for further analyses (120 individual observations). All matches were played on natural-grass soccer pitch. Air temperature was 18.1 ± 3.7°C with a relative humidity of 61.2 ± 21.5%, respectively. The validity of the GPS unit utilized in the present study was previously assessed in a previous study (Bellistri G et al., 2016). The data recorded during the matches were exported using specific software (K-Fitness, K-Sport, Italy) and subsequently combined in a customized spreadsheet for analysis.

Statistical Analysis

Data are expressed as means ± standard deviations (SD). Before analysis, the data about VT_2 speed threshold, total and high-intensity distance were checked for normality using a Shapiro-Wilk test and found to be normally distributed. A paired t-test was used to determine the difference in HID measured using FEM versus MALE threshold (Prism 6.0; GraphPad, San Diego, CA, USA). Statistical significance was set at $P<0.05$. Effect sizes (ES) were calculated to determine the meaningfulness of the difference with the magnitudes classified as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2) and large (>1.2) (Batterham AM, Hopkins WG, 2006).

RESULTS

Incremental test

Maximal oxygen consumption measured during incremental test was 49.1±3.7 $ml \cdot kg^{-1} \cdot min^{-1}$ and occurred at a speed value of 14.7±0.8 $km \cdot h^{-1}$. The mean value of the respiratory compensation threshold (VT_2) was 42.2±4.6 $ml \cdot kg^{-1} \cdot min^{-1}$ corresponding at the 85.9±2.8 % of the maximal oxygen consumption. The mean VT_2 speed (FEM) was 13.47±0.97 $km \cdot h^{-1}$ with a median of 13.51 $km \cdot h^{-1}$ and a range of 12-14.5 $km \cdot h^{-1}$. The difference between the FEM and MALE speed was of 1.5 $km \cdot h^{-1}$ corresponding at a reduction of 10% in speed threshold.

Match analysis

The total distance covered was 7726±891 m. High-intensity distance (HID) assessed using FEM threshold (1125±533 m) was significantly higher than when it was assessed using MALE threshold (785±353 m) ($P<0.05$) (figure 7.1). The Cohen effect size for the difference is 1.52 (95% CI: 1.37 to 1.68, large effect). When expressed as percentages of TD, HID was 14.4±5.8 % in FEM and 9.9±3.8 % in MALE. The Cohen effect size for the difference expressed in % was 1.74 (95% CI: 1.47 to 1.98, large effect).

DISCUSSIONS

The main results of the present study showed that the speed at the second ventilatory threshold of elite female soccer players was 13.5 $km \cdot h^{-1}$ that was lower than that reported for their male counterpart and that high-intensity distance was significantly higher when assessed using specific high-intensity threshold.

The default speed threshold used in the present study to analyse high-intensity distance was 15 km·h^{-1}. Different studies used this speed threshold in male soccer players (Krustrup et al., 2005; Mohr et al., 2008; Andersson et al., 2010; Andersson, Ekblom, & Krustrup, 2008; Bangsbo et al., 1991). Mohr et al. (2003) showed that there is a significant difference in high-intensity distance between top class and moderate professional soccer players covering ~22% and ~18% of the total distance at a speed exceeding 15 km·h^{-1}, respectively, underling the importance of this match indicator in soccer. In UEFA and international female soccer players the high-intensity distance covered during a match was ~1300m corresponding at ~14% of total distance (Andersson et al., 2010; Bradley et al., 2014; Krustrup et al., 2005; Mohr et al., 2008). In the present study, the total high-intensity distance covered was ~800m, significantly lower than that reported on literature. A possible explanation of this discrepancy could be due to a lower intensity level in Italian female soccer compared to other country in which there is a stronger expansion (http://www.uefa.org/MultimediaFiles/Download/uefaorg/WFprogramme/02/20/39/67/2203967_DOWNLOAD.pdf). We exclude a difference in aerobic fitness level; in this study, we found a $VO_{2maxspeed}$ of 14.7 km·h^{-1} in accordance with other previous studies that reported similar (Ingebrigtsen et al., 2011) or lower speed (Dillern et al., 2012).

The rationale for the choice to use typical male speed threshold (>15 km·h^{-1}) is originally based on an estimate of exercise intensity (soccer running) close to the speed for maximal oxygen uptake (VO_{2max}) (Bangsbo,1994; Greig,McNaughton,&Lovell,2006). To use the same threshold in female could not be totally appropriate. Different studies analysed the VO_{2max} in male and female soccer players and showed that the corresponded speed measured during treadmill test ($VO_{2maxspeed}$) was significantly lower in female than in male (Ingebrigtsen et al., 2011; Sirotic et al., 2007; Labsy et al., 2004; Castagna et al., 2006). The reported values of $VO_{2maxspeed}$ were about 17 km·h^{-1} in male and 14.5 km·h^{-1} in female soccer players. Considering these values, the speed threshold of 15 km·h^{-1} corresponds at 88% and

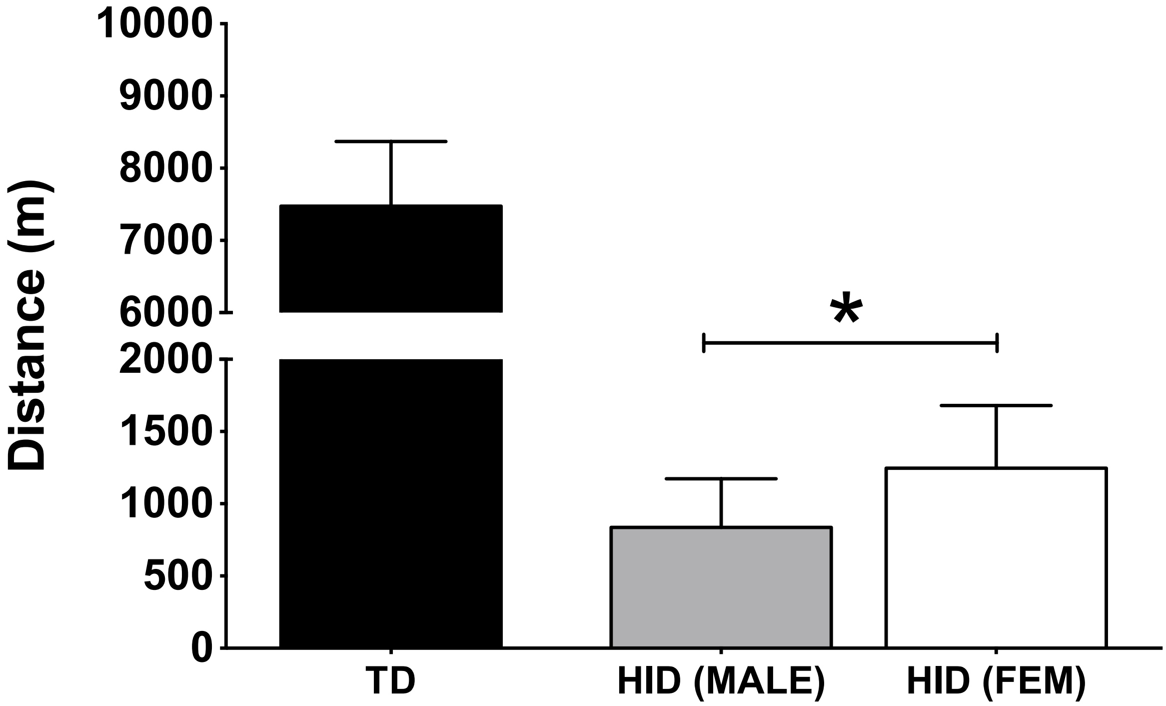
103% of $VO_{2maxspeed}$, respectively. Abt et al. (2009) assessed second ventilatory threshold in male soccer players and reported a speed threshold of 15 km·h^{-1}, showing that the speed that for female represent a value greater than their $VO_{2maxspeed}$, for male represent only the transition between moderate and high-intensity exercise (Esteve-Lanao, San Juan, Earnest, Foster, & Lucia, 2005; Lucıa, Hoyos, Pe´rez, & Chicharro, 2000). An athlete exercising at an intensity above this point will usually display an inability to sustain exercise (Davis, 1985; Wasserman, 1984), in male soccer players this speed is very close to 15 km·h^{-1} but for female the physiological meaning is totally different.

The choice to use individual o specific threshold is an actual discussion topic and it have received increasing attention. Aerobic fitness differences have been showed not only during treadmill test performed on laboratory but also during field-based intermittent test such as Yo-Yo Intermittent recovery test level 1 (Yo-Yo IRT1) that is regarded as a good measure of aerobic-anaerobic indices widely used in team sport (Krustrup et al., 2003). A strong relationship has been shown between Yo-Yo IRT1 and $VO_{2maxspeed}$ (Castagna et al., 2006) obtained on treadmill. Bradley & Vescovi, in 2015, suggested using the velocity obtained at Yo-Yo IRT1 termination as an individual or specific high-speed threshold in male and female soccer players. This could be an interesting approach because of the specificity of the test in soccer. Moreover, authors critiqued the use of the second ventilator threshold in soccer because the questioned sport have intermittent nature instead this threshold is related to continuous exercise suggesting to use $VO_{2maxspeed}$. Conversely Abt et al. (2009) suggested that the absolute high-intensity speed threshold of 15 km·h^{-1} is the most appropriate of the many absolute high-intensity speed thresholds used in male soccer players because there is a physiological meaning and because of the is the most used in different studies to differentiate between levels of play in both female and male players, to analyse the physiological changes associated with the completion of a training programme and to variations in stages of the competitive season and tactical role of players (Di Salvo et al., 2009). Different approaches are possible to find a gender-specific threshold, but the most important thing should be to have the same physiological meaning in male and female to try to make appropriate consideration on match profile.

CONCLUSIONS

In conclusion, we found that the second ventilator threshold in female soccer players was ~13.5 $km \cdot h^{-1}$ and considering the speed at maximum oxygen uptake reported from other studies this speed could be use not only for elite Italian female soccer players but also for international players. Research is needed with female players across various considerations about high-intensity distance covered during match as it has already been done for men to understand the importance of high-intensity distance to differentiate performance level, or to understand the development of fatigue during match.

Figure 7.1 Total distance (black column) high-intensity distance calculated using threshold of 15 km·h^{-1} (grey column) and high-intensity distance calculated using specific-threshold (white column).



Study 4

Muscle performance impairment after different training modalities in adult soccer players: small-sided games vs interval running

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Running head: Muscle fatigue in different soccer training modalities

In preparation

ABSTRACT

Aim. Several studies showed that either small-sided games (SSG) or interval running (IR) increases aerobic power in soccer players. However, SSG differ from IR in the great number of accelerations/decelerations and changes of direction which may affect muscle function. The aim of this study was to evaluate impairment of muscle performance after SSG and IR sessions of similar heart rate (HR) intensity.

Methods. Fifteen soccer players were recruited and performed two different training sessions (SSG and IR) with the same duration (4x4 min, 3 min active rest periods) and related HR intensity (90-95% of HRmax). During each session players wore a portable GPS device and the HR was recorded. Maximum voluntary contraction of quadriceps (MVC), counter movement jump (CMJ) and reactive strength index in drop jump (RSI) were assessed before (T_0), immediately after (T_1) and 24 hours after (T_{24}) each session.

Results. Time spent at various HR intensity zones was similar between SSG and IR. Total and high-intensity distances, average metabolic power, distance covered at high MP (<20 $w \cdot kg^{-1}$) were significantly lower in SSG than in IR. The number of accelerations/decelerations was significantly higher in SSG. At T_1 vs T_0, MVC, CMJ and RSI were significantly decreased in SSG and IR respectively. Despite at T_{24} muscle performance was impaired in SSG, no differences were observed in IR vs T_0.

Conclusions. The present findings suggest that despite the similar HR intensity, muscle performance impairment was more pronounced and persisting after SSG. The differences observed between the two training modalities could be explained by the higher number of accelerations/decelerations in SSG.

INTRODUCTION

In recent years, several studies showed that small-sided games (SSG) could be used as an effective tool for aerobic training for soccer players (Impellizzeri et al., 2006). Coaches often choose SSG in order to improve soccer-specific endurance capacity, to train specific muscle-groups, to improve technical and tactical abilities and to assume an effective transfer to match play (Halouani et al., 2014). Impellizzeri and colleagues (2006) compared the effect of aerobic fitness in soccer players following 8 weeks of two different aerobic training stimulus: interval running training vs SSG. They used interval training as suggest by Helgerud et al. (2001) and proposed 4 bouts of 4 min at 90 – 95 % of maximum heart rate with 3 min active rest periods. It was previously demonstrated (Helgerud et al., 2001) that this intervention improved $V'O_{2max}$, lactate threshold, running economy at lactate threshold and total distance covered during match. Comparing these methods, Impellizzeri et al. (2006) have found no differences after 8 weeks of training on aerobic performance between SSG and aerobic interval training and the authors concluded that the choice of the aerobic training mode should be based mainly on practical necessity.

However, SSG impose a different stimulus than traditional interval training. An activity as soccer impose high musculoskeletal loads on players, due to the repeated maximal intermittent muscle actions, such as accelerations/decelerations phases, jumps and changes of direction (Sheppard et al., 2009). After a match, these stimuli cause muscle fatigue and damage of various degrees and may trigger inflammatory responses (Souglis et al., 2015; Apostolidis et al., 2014). Fatigue is generally defined as any decline in muscle performance associated with muscle activity (Allen et al., 2008) and the reduction in voluntary activation may be because of inhibition caused by muscle soreness (Nedelec et al., 2014). These responses are typical in specific-soccer activity, but in running without change of direction or accelerations/decelerations phases these are probably absent or at least different.

These different acute reactions could impair muscle function in distinct ways. Coaches should know these different answers to better choose the more appropriate aerobic training mode, but to our knowledge no studies have investigated the different muscle performance impairment after SSG vs running training.

The aim of this study was to compare the decay of muscle performance after soccer-specific aerobic and traditional interval running training sessions.

METHODS

Subjects

Fifteen non-professional soccer players were recruited in this study during off-season. Mean age, stature, body mass and body mass index were 23.5 ± 2.1 years, 176.9 ± 8.2 cm, 70.7 ± 7.9 kg and 22.6 ± 1.4 $kg \cdot m^{-2}$, respectively. Players possessed at least 5 years of experience in soccer training and competitions.

Experimental design

We used a cross-over study design to examine the effect of two different training sessions. Each player performed a YO-YO intermittent recovery test level 1 (YYIRT1) to evaluate fitness level and individual maximal heart rate (HRmax). All players were familiarized with the test used during the experimental phase. Subjects were matched and randomized in two groups. Two different training sessions (small-sided games: SSG and interval running: IR) with the same duration and relative HR intensity (90-95% of HRmax) were performed in a crossover study. After one week of recovery, each group performed the second training session. During each session GPS and HR data were collected. Maximum voluntary contraction of quadriceps (MVC), counter movement jump (CMJ) and reactive strength index in drop jump (RSI) were assessed before (T_0), immediately after (T_1) and 24 hours after (T_{24}) each session.

Physical assessment

YYIRT1 was performed at progressively increasing velocity controlled by audio bleeps from a CD player and interspersed with 10 s of active recovery after every out and back shuttle. The test was ended when a player failed twice to reach the appropriate marker or the player felt unable to complete another shuttle at the required speed. The total distance covered during the test and HRmax were recorded as the test result.

To assess maximum voluntary force subjects were set on a custom-made bench, arms folded across the chest, the angle between trunk and thigh was at 135° and the knee joint angle was set at 90° of flexion. The trunk and hip was firmly fixed using two belts. Ankle was attached with a noncompliant strap and connected to a calibrated load cell by a non-deformable metallic rod to determine voluntary quadriceps force. Three MVC were performed and were separated by 30 s of rest from one to another and to maximize force output strong verbal encouragement were given from the same investigators.

Players performed three CMJ keeping their hands on the hips during the jump to prevent any influence of arm movements and the best jump was classed as the criterion measure. Jump height was estimated from flight time using photocell mat (Optojump, Microgate, Italy) connected to a portable computer.

To examine RSI a depth jump at height of 30 cm was performed. Subjects were instructed to “step out” from the box 1 foot at a time and to not jump from the box and on contact with the force platform (Optojump, Microgate, Italy) to jump as high as possible, as quickly as possible.

Training sessions

Each session was performed after a 20-minute warm-up, which consisted of low-intensity running, striding, skipping and stretching. In IR players run around the regular soccer pitch without change of directions and accelerations/decelerations phases. The SSG selected was: 3 vs. 3, without goalkeeper, 18 x 30 m pitch dimension according to Rampinini et al. (2007). Duration and intensity both in SSG and IR were: 4 bouts of 4 min at an intensity corresponding to 90-95% of HRmax with 3 min of active rest periods at an intensity of 60-70% of HRmax. During each session, HR was recorded and monitored using short-range telemetry systems (Vantage NV, XTrainer, S610 and S710 models, Polar, Kempele, Finland). Investigators verbally encouraged to maintain the correct intensity. Lactate concentration was assessed after 2 and 4 minutes the end of each session training to examine the peak value.

During each session players wore a portable GPS device with a sampling rate of 15 Hz (SPI Pro, GPSports). Total distance (TD), equivalent distance (EqD), equivalent distance index (EqI, calculated as ratio between TD and EqD, Osgnach et al., 2010), average metabolic power (AvMP), distance covered at high metabolic power (> 20 $w \cdot kg^{-1}$) (HMPD), number of accelerations/decelerations and number of high intensity accelerations (> 2.78 $m \cdot s^{-2}$) and decelerations (< -2.78 $m \cdot s^{-2}$) were analysed as indicators of external load.

Statistical analysis

Data are reported as means ± standard deviation (SD). Differences between protocols 1) in time spent in the selected HR zones during the two training sessions (<80%, 80%-90% and >90% of HRmax), 2) in peak of lactate concentration at T_1 and 3) for all GPS data were analysed using paired t-tests. One-way analysis of variance (ANOVA) with repeated measures was used to determine differences between T_0, T_1 and T_{24} for each muscle evaluation both in SSG and in IR. The differences of the percentage decrement at T_1 and at T_{24} in SSG vs IR were also analyzed using ANOVA with repeated measures. Tukey's post-hoc test was used to verify localized effects. Statistical significance was set at $P<0.05$. Based on mean and standard deviations for the MVC, CMJ and RSI variables obtained in preliminary trials conducted in healthy men before the experimental phase, a minimum N value of 14 was calculated to be sufficient to detect significant differences between session, if present, with an alpha level of 0.05 and a beta level of 0.20 (Prism 6.0, GraphPad, San Diego, CA, USA). All analyses were performed using statistical software package (Prism 6.0; GraphPad, San Diego, CA, USA).

RESULTS

Total distance covered during YYIRT1 was 1750 ± 258 m and HRmax reached during YYIRT1 was 190 ± 3 bpm. Table 7.1 shows the differences between SSG and IR in GPS data and it shows that TD, EqD, AvMP and HMPD in IR were significantly higher than in SSG ($P<0.01$), but EqI, number of accelerations/decelerations and number of high intensity accelerations/decelerations were significantly higher in SSG than in IR ($P<0.01$).

No differences were found in time spent at HR intensity zones (figure 8.1).

The maximum force output in MVC (figure 8.2), height in CMJ (figure 8.3) and RSI measured during depth jump (figure 8.4) at T_1 were significantly reduced from T_0 after SSG and after IR ($P<0.01$). These decrements were significant at T_{24} only after SSG ($P<0.01$) and not after IR.

The percentage decrements measured at T_1 vs T_0 in SSG for MVC force (-17.0 ± 7.5 %), CMJ height (-11.1 ± 4.1 %) and RSI (-15.8 ± 7.1 %) were significantly higher ($P<0.01$) than in IR (-7.4 ± 4.6 %, -5.2 ± 6.2 % and -6.1 ± 4.4 % respectively).

DISCUSSIONS

In agreement with our hypothesis, muscle performance impairment after small-sided games session was greater than after interval running session. In particular way, maximum voluntary contraction of quadriceps, height in counter movement jump and reactive strength index after depth jump were significantly impaired immediately after both aerobic session mode, but the performance decrement was significantly higher after soccer-specific training session. Furthermore, only after small-sided games session the muscle impairment remained significantly lower after 24 hours.

The time spent at every heart rate zone was not different in small-sided games vs interval training. As shown by Helgerud et al. (2001), many of the effect of aerobic interval training was due to the high time spent at high heart rate intensity (>90% of heart rate maximum). Our results showed that the heart rate intensity was similar in small-sided games and in interval running training session. Several studies that investigated the heart rate intensity in small-sided games have found similar results (Impellizzeri et al., 2007; Koklu, 2012; Koklu et al., 2012; Koklu et al., 2011). We could assert that the relative heart rate intensity was the same both in training sessions.

In the last decades, the global positioning systems (GPS) evolved and permitted valid and reliable estimates of the external load during activity in team sport activity (Brandes et al., 2012; Casamichana & Castellano, 2010; Castellano et al., 2013; Dellal et al., 2011). It seems important to quantify not only the distance covered at certain speeds but to evaluate also the explosive actions and changes in velocity and direction that implies a higher workload (Gaudino et al., 2014). Our findings showed that, during interval running session, players covered more total distance, more distance at a high metabolic power; equivalent distance and average metabolic power were greater than in small-sided games session. In contrast, the number of accelerations/decelerations was negligible in the interval running (~ 2) but it was very great in small-sided games session (113) and consequently also the equivalent distance index (1.02 vs. 1.29). The high number of accelerations/decelerations phase could explain the different muscle impairment in two aerobic session mode. Several studies (Nedelec et al., 2014; Chatzinikolaou et al., 2010; Howatson and Milak, 2009) have demonstrated that these high intensity actions induce muscle damage and their frequency might affect the time to fully recover after competition. Moreover, Young et al. (2012)

demonstrated that these were large contributors to muscle damage estimated by determining creatine kinase (CK) concentrations 24 hours after match.

In agreement with our findings, Nedelec et al. (2014) found a correlation between total high intensity playing action (including jump, accelerations/decelerations phases, sprint and change of direction) performed during the match and decrements in CMJ performance and in MVC of the hamstring muscles 24 hours after the match. The reactive strength index describes the ability to switch quickly from an eccentric to concentric muscular contraction and it has been developed as a mechanism to monitor the stress on the musculotendinous complex during plyometric exercises (Flanagan et al., 2008). The complexity of specific soccer movements requires often explosive and powerful and the form of a stretch-shortening cycle (Comyns et al., 2011). In 2011 Comyns et al. have showed a reduction in jumping performance and reactive strength index in male rugby players immediately after heavy intensity exercise. They observed that the fatigued workout had a negative effect on the ground CT and consequently on reactive strength index. According to these results our findings showed a significantly reduction in stretch-shortening cycle, and this decrement were more evident in soccer-specific session than in interval running, probably due to a higher number of high intensity eccentric activities such as accelerations and decelerations.

In conclusion, the present findings suggest that despite the similar HR intensity, muscle performance impairment was more pronounced and persisting after SSG. The differences observed between the two training modalities could be explained by the higher number of accelerations/decelerations in SSG. These results could help coaches and sport scientists to better create their training program in relation to team weekly planning and calendar.

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Figure 8.1 Average time spent at different intensities as expressed in percent of maximum heart rate (HRmax) during the training sessions. SSG, small-sided games; IR, interval running.

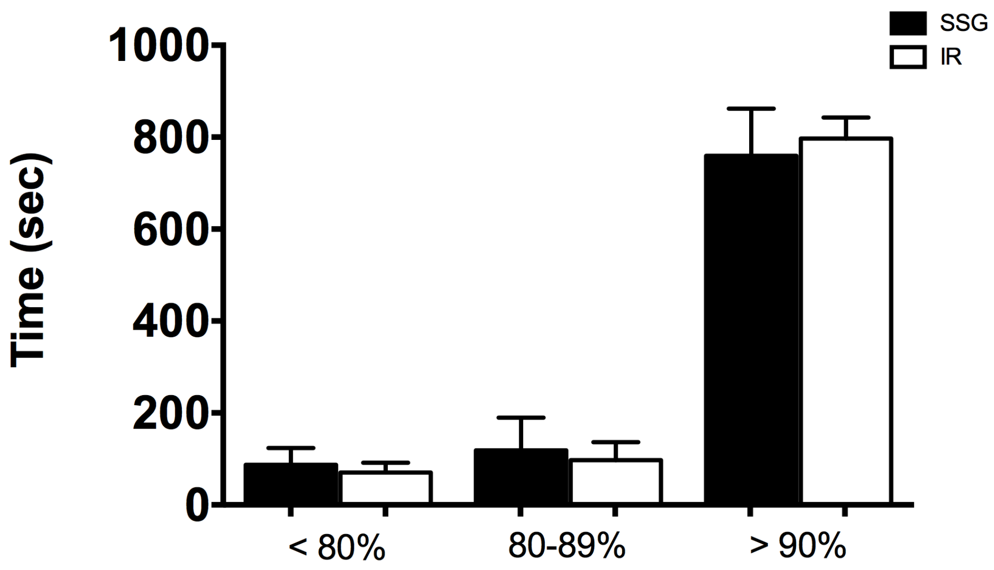


Figure 8.2 Weight measured during maximal voluntary contraction before (T_0), immediately after (T_1) and 24h after (T_{24}) small-sided game session (a) and interval running session (b). *Significantly different from T_0 ($P<0.05$); #Significantly different from T_1 ($P<0.05$).

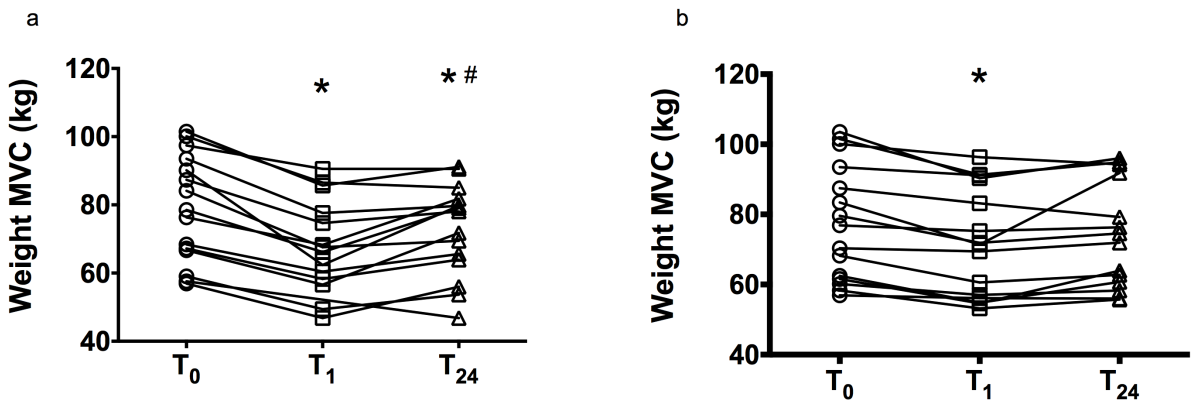


Figure 8.3 Height measured in counter movement jump before (T_0), immediately after (T_1) and 24h after (T_{24}) small-sided game session (a) and interval running session (b). *Significantly different from T_0 (P<0.05).

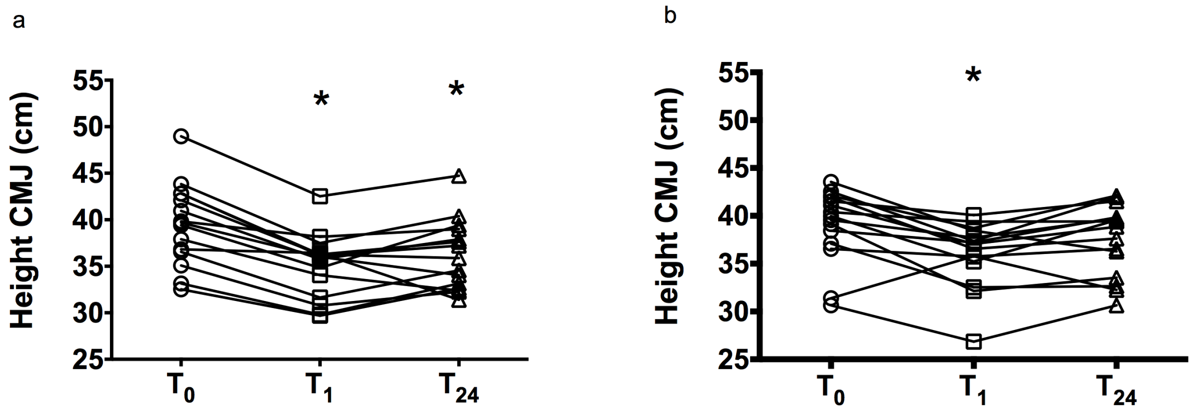
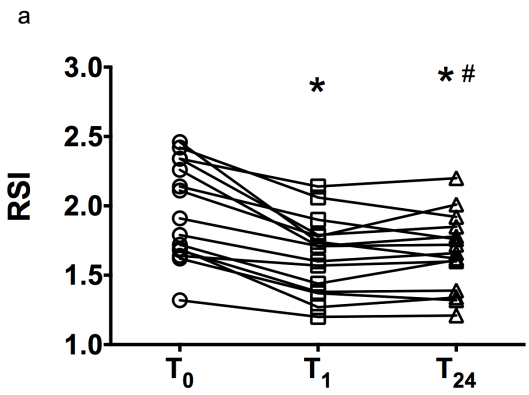


Figure 8.4 Reactive strength index measured in drop jump before (T_0), immediately after (T_1) and 24h after (T_{24}) small-sided game session (a) and interval running session (b). *Significantly different from T_0 (P<0.05); #Significantly different from T_1 (P<0.05).



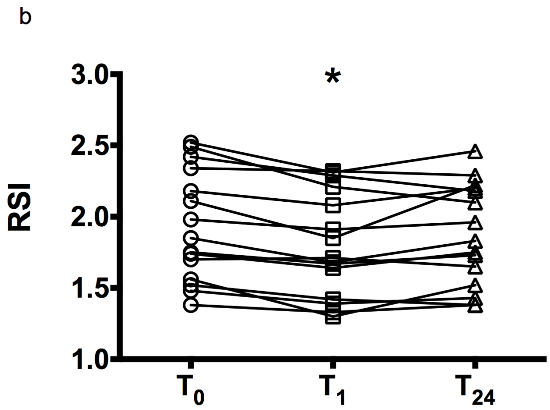


Table 7.1 External load by GPS data.

	TD m	EqD m	EqI	HMPD m	AvMP $w*kg^{-1}$	Acc/Dec n°	HI Acc/Dec n°
SSG	2156 ± 136*	2778 ± 211*	1.29 ± 0.04#	724 ± 114*	13.5 ± 0.9*	113 ± 25#	30 ± 14#
IR	3802 ± 188	3886 ± 191	1.02 ± 0.03	1445 ± 373	18.6 ± 0.9	2.60 ± 2.71	0.51 ± 1.01

TD: total distance; EqD: equivalent distance; EqI: equivalent distance index; AvMP: average metabolic power; Acc/Dec: accelerations and decelerations; HI: high intensity acceleration (> 2.78 $m \cdot s^{-2}$) and decelerations (< -2.78 $m \cdot s^{-2}$); IR: interval training session; SSG: small-sided games session.

* significantly lower than IR (P<0.05); # significantly higher than IR (P<0.05).

Final considerations

The aims of this series of investigations were: (1) to examine the accuracy of GPS technologies in soccer-specific activities; (2) to evaluate physical and physiological demands in different population, such as very young soccer players and (3) female soccer players; (4) to investigate the muscle performance impairment after two different training modalities and the impact of external load measured using GPS device.

The use of GPS technologies represents a new approach to better describe the physical demand and external workload in soccer. The main discussed problem in using GPS device is the accuracy and validity of this system in a sport like soccer in which different types of high-intensity activities coexist. Some studies have reported that the sampling rate is an important parameter to improve measure of exactitude in short-high intensity activities and the reliability of GPS devices gradually decreases in relation to increasing number of changes of directions and accelerations and to the reduced running distance (Castellano et al., 2011; Jemmings et al., 2010; Portas et al., 2010). In 2016, Nagahara et al., showed that concurrent validity for obtaining mechanical properties during straight-line sprint acceleration was better when using 20Hz GPS device than that obtained from 5Hz GPS device, but for our acknowledgment this is the only study about GPS device with a sampling rate of 20 Hz. The findings reported in our study are in accordance with previous research showing that the accuracy of GPS device is better in 20Hz GPS than in GPS-10Hz for measuring mean and peak speed in short shuttle sprints. However, even the outcomes from the 20 Hz GPS unit showed differences. Moreover, it is unclear if the new metabolic approach proposed by di Prampero et al. (2005) and Osgnach et al. (2010) could be correctly used in order to estimate the energy expenditure in soccer. There are some criticisms and limitations about this approach. Stevens et al. (2014) compared the energy cost of 180- changes of direction during continuous shuttle running to the values estimated by di Prampero's approach. Using the di Prampero's approach, the authors showed the energy cost overestimated during the constant running, whereas for shuttle running, the energy cost was underestimated. At the same time, this is the first model that tries to estimate energy expenditure in a multifactorial team sport like soccer, considering also the acceleration and deceleration phases of running. Other researches are needed to better understand how to solve these problems.

The second study about match running performance and physical capacity profiles in very young soccer players showed how our results are in contrast with that reported in literature for adult soccer player. The total workload and high-intensity distance were significantly different between the two age groups (U8 and U10), but this could be related to the reduced physical capabilities in very young soccer players. The most surprising information is shown when data was split into distinct time periods to understand the occurrence of fatigue throughout the match. In contrast with different studies in young (Rebelo et al., 2014) and adult (Mohr et al., 2003) soccer players, the present study found no decrement in total and high-intensity running distances during U8 and U10 matches. Thus, the present findings potentially highlight a fatigue pattern during matches in relation to age. This information could help to analyse match in very young soccer players considering the different muscle physiology of this population and to describe the match demand to program a correct training plan in very young soccer players.

Female soccer players represent another population worthy of attention. In the last years, the women's match physical performance has received increasing attention (Andersson et al, 2010; Mohr et al. 2008). Despite an increasing of women's soccer players studies that describe the high-intensity activity in women's soccer match compared to men soccer players (Andersson et al, 2010; Mohr et al. 2008). Consequently, there is no methodological universally agreed upon of high-intensity speed threshold (Bradley & Vescovi, 2015). In male soccer players the speed thresholds used to delimit the high-intensity zone have been define between a range from 13 $km{\bullet}h^{-1}$ to 19.8 $km{\bullet}h^{-1}$ (Mallo et al., 2007; Rampinini et al., 2007a; Rampinini et al., 2007b; Andersson et al., 2008; Bangsbo et al., 1991; Castagna & D'Ottavio, 2001; Di Salvo et al., 2007; Weston et al., 2007). However, the most used speed threshold in male soccer players seems to be 15 km•h^{-1} (Abt et al, 2009; Andersson et al., 2008; Bangsbo et al., 1991). The latter appears to be more correlated to the second ventilator threshold in elite male soccer players (Abt et al., 2009). Here because, in different female study, to analyze high-intensity distance were used the same speed threshold of males. However, this approach seems to be unappropriated considering that physical capabilities in female soccer players are significantly lower than in male soccer players. In our study, we proposed to use a specific-speed threshold to analyze the high-intensity distance covered in female soccer match. The second ventilator threshold in elite female soccer players is ~13.5 km·h^{-1} and if the researches aim to do the same speculations about high-intensity distance a specific gender speed threshold with the same physiological meaning should be used.

Finally, the GPS device could help to better understand the intensity and muscle impact in different training modalities, even if the data used in relation to type of exercise is still unclear. In the last presented study, we investigated muscle performance impairment after different training modalities: small-sided games *versus* interval running. We found that maximum voluntary contraction of quadriceps, height in counter movement jump and reactive strength index after depth jump were significantly impaired immediately after both two-aerobic session mode, but the performance decrement was significantly higher after soccer-specific training session. Furthermore, only after small-sided games session the muscle impairment remained significantly lower after 24 hours. Moreover, in contrast with the theory that *"more work load produces more fatigue",* during interval running session, players covered more total distance, more distance at a high metabolic power, more equivalent distance and average metabolic power than in small-sided games session, but the muscle impairment is greater in small-sided games than in interval running. Only the number of accelerations/decelerations was negligible in interval running (~ 2) but it was very great in small-sided games session (113) and consequently also the equivalent distance index (1.02 vs.

1.29). This data could explain the different muscle impairment in two aerobic sessions mode. In this contest, the use of GPS device could help to better understand the correct external workload and/or intensity, since choosing the output data in relation to the training modalities.

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List of Publications

- **Bellistri G**, Rejc E, Porcelli S. Accuracy and reliability of a 20Hz GPS device for measuring mean and peak speed of shuttle sprints. In preparation.
- **Bellistri G**, Marzorati M, Giudici A, Sforza C, Porcelli S. High-Intensity distance in elite female soccer players based on a gender-specific threshold. In preparation.
- **Bellistri G**, Mauro Marzorati M, Sforza C, Muratore M, Oddo A, Porcelli S. Muscle performance impairment after different training modalities in adult soccer players: small-sided games vs interval running. In preparation.
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Conference Presentations During Candidature

- **Bellistri G**, Muratore M, Oddo A, Corti F, Giordano D, Porcelli S. Muscle performance impairment after different training modalities in adult soccer players: small-sided games vs interval running. SISMES, Roma 8-10 October 2016.
- **Bellistri G**, Oddo A, Muratore M, Sforza C. The effects of PHV on physical performance on young soccer players. ECSS, Vienna 6-10 July 2016.
- **Bellistri G**, M. Marzorati, C. Sforza, A. La Torre, A. Giudici, A. Oddo, M. Muratore, S. Porcelli. The role of individual thresholds to monitor training load in elite young soccer players. SISMES, Padova 2-4 October 2015.
- Rasica L, Pavei G, **Bellistri G**, Ramaglia M, Crociani B, Marzorati M, Porcelli S. Energy cost of backward running at positive gradients. ECSS, Malmö 24-27 June 2015.
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- **Bellistri G**, Sodero L, Ramaglia M, Sforza C, Marzorati M, Porcelli S. Physical capacity and match running performance in very young soccer players. 8th World Congress on Science and Football, WCSF Copenhagen 20-23 May 2015.
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- Ramaglia M, **Bellistri G**, Marzorati M, Sodero L, Zuccarelli L, Bisconti V, Porcelli S, F. Veronesi. Evaluation of skeletal muscle oxidative metabolism in Alzheimer disease patients. SISMES Napoli 27-29 September 2014.

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- Ramaglia M, **Bellistri G**, Annoni S, Crociani B, Rasica L, Marzorati M, Porcelli S. Effects of nitrate supplementation on aerobic performance in subjects with different fitness level. ECSS, Amsterdam 2-5 July 2014.
- Porcelli S, Marzorati M, **Bellistri G**, Morandi L, Grassi B. New methods of functional evaluation of patients with metabolic myopathies. The effects of exercise training. ECSS, Amsterdam 2-5 July 2014.

Courses and Workshop as student

- “L'allenamento del giovane calciatore: dalla teoria alla pratica.” Department of Biomedical Sciences for Health, University of Milan, Milano, 2014.
- “Physiological sciences in Berlin and Milan: from past to future.” Department of Biomedical Sciences for Health, University of Milan, Milano, 2014.
    - The Charité Medical University. “Past, present and future”. Hanns-Christian Gunga, Professor of Physiology, Charité – Universitätsmedizin, Berlin.
    - “Brain Function, Cognitive Performance and Physical (In) Activity: Recent Insights into Mechanisms and Countermeasures from Research in Extreme Environments.” Alexander Stahn, Center for Space Medicine Berlin, Charité – Universitätsmedizin, Berlin.
    - “The Double Sensor Applications of a non-invasive heat-flux sensor on Earth and in space.” Hanns-Christian Gunga Professor of Physiology, Charité – Universitätsmedizin, Berlin.
- “The physiology of neuroendrocrine system: the overall control of metabolic processes during exercise”. Dr. Randy W. Bryner. Department of Biomedical Sciences for Health, University of Milan, Milano, 2014.
- “The immune system: the physiological effects of acute and chronic exercise and its clinical significance”. Dr. Randy W. Bryner. Department of Biomedical Sciences for Health, University of Milan, Milano, 2014.
- “Perdita di massa e muscolare con l'invecchiamento: perché il muscolo dell'anziano è così debole?” Prof. Marco Narici. Department of Biomedical Sciences for Health, University of Milan, Milano, 2014.
- “Introduzione ai metodi per l'analisi di misure seriali nella ricerca biomedica”. Department of Biomedical Sciences for Health, University of Milan, Milano, 2014.

- “General linear model and experimental design using R”. Department of Biomedical Sciences for Health, University of Milan, Milano, 2015.
- “Come pubblicare con successo sulle riviste scientifiche piú importanti a livello internazionale”. Department of Biomedical Sciences for Health, University of Milan, Milano, 2015.
- Sozen lectures: “Assessment of skeletal muscle functionality: from basic physiology to recent advances”. Department of Biomedical Sciences for Health, University of Milan, Milano, 2015.
- “Effects of lumbosacral spinal cord epidural stimulation for the recovery of motor function after chronic complete paralysis in humans”. Enrico Rejc. Institute of Bioimaging and Molecular Physiology (IBFM), National Research Council (CNR), Segrate (MI), 2015.
- “Effects of nitrate supplementation on muscle blood flow during high intensity forearm exercise”. Lorenzo Pugliese. Institute of Bioimaging and Molecular Physiology (IBFM), National Research Council (CNR), Segrate (MI), 2015.
- “Effects of dietary nitrate supplementation on exercise tolerance in obese adolescents.” Letizia Rasica. Institute of Bioimaging and Molecular Physiology (IBFM), National Research Council (CNR), Segrate (MI), 2015.
- “Effects of muscle composition and architecture on specific strength in obese older women.” Fabio Rastelli. Institute of Bioimaging and Molecular Physiology (IBFM), National Research Council (CNR), Segrate (MI), 2015.
- “Periodizzazione dell'allenamento e Metodi delle attività sportive.” Luca Guercilena. Department of Biomedical Sciences for Health, University of Milan, Milano, 2015.
- “L'allenamento e la valutazione funzionale: prevenzione degli infortuni e miglioramento della prestazione”. Centro Diagnostico Italiano, Gruppo Bracco. Milano, 2015.

- “Sport Medicine.” Prof. Daniela Lucini, Department of Biomedical Sciences for Health, University of Milan, Milano, 2016.

Courses and Workshop as teacher

- "The role and determination of Critical Power." Giuseppe Bellistri. Institute of Bioimaging and Molecular Physiology (IBFM), National Research Council (CNR), Segrate (MI), 2015.
- "La valutazione del calciatore: dalla fisiologia alla pratica." Giuseppe Bellistri. University lesson in "General & Sport Physiology". Catholic University of the Sacred Heart, Milano, 2015.
- "Exercise intensity thresholds: identifying the boundaries of sustainable performance." Giuseppe Bellistri. Institute of Bioimaging and Molecular Physiology (IBFM), National Research Council (CNR), Segrate (MI), 2015.
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- "Inter academy method: Training load monitoring in order to prevent injuries." Giuseppe Bellistri. Inter Academy lesson, Milano, 2016.
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- "Il giovane calciatore: Evoluzione della performance e controllo del carico." Giuseppe Bellistri. Lesson in Master in "Fitness coach for young soccer players". Catholic University of the Sacred Heart, Milano, 2016.

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